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WORKLOAD ANALYSIS OF A MILITARY REPAIR DEPOT

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THESIS

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THESIS

Presented to the Faculty of the School of Engineering

of the Air Force Institute of Technology

Air University

in Partial Fulfillment of the

Requirements for the Degree of

Master of Science

by

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Captain USAF

Graduate Operations Research

September 1975

PREFACE

This paper examines the costs of operating a military repair depot and presents an approach for total workload analysis. Specifically, the depot examined was the Aerospace Guidance and Metrology Center, located at Newark, AFS, Ohio.

I am indebted to many people for their contributions in this effort. My advisor, Dr. N.K. Womer, played a vital role in completing this project. His guidance is represented in every topic discussed. Mr. Russ Genet, Mr. Dick Rogge, and others at the Aerospace Guidance and Metrology Center provided valuable assistance in collecting information and outlining a workable approach to this analysis. I wish to thank Major Jon Hobbs, Ph. D., for his guidance as thesis reader.

Above all, I am grateful to my wife, [redacted] who typed this thesis, and to my children, [redacted] and [redacted]

Donald A. Clark

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ABSTRACT

Depot sizing is a topic of concern to the Air Force. Determination of the proper size of a repair depot requires a close look at the effects of volume level and economies of scale upon depot costs. In this analysis, direct labor, direct material and overhead costs are examined as time and volume levels change. An output measure is presented as well as an approach for use in workload analyses.

Specifically, this study centers on the Aerospace Guidance and Metrology Center (AGMC) located at Newark AFS, Ohio. Eighteen end items repaired at the depot are examined individually to find trends and possible indicators of cost behavior. Relations for estimating direct labor hours, direct labor costs, direct material costs, and overhead costs are derived for 12 end items using least squares regression techniques. Direct labor hours, time, and units of output were generally found to be significant independent variables.

The "measure of merit" problem is examined with respect to finding a workload mix and volume level which is cost effective. An approach to workload analysis is presented which measures the effect on the existing depot workload of adding or deleting an end item. The approach is illustrated using four products currently in the AGMC workload.

CHAPTER 1
INTRODUCTION

STATEMENT OF THE PROBLEM

The level of production and the mix of products repaired at the Air Force Logistics Command repair depots are subject to continual fluctuation. The Air Force Logistics Command, specifically in this analysis the Aerospace Guidance and Metrology Center, Newark, Ohio, desires research into the total relative costs associated with various levels of production and mixes of workload.

BACKGROUND

The costs of repairing weapon system components represent a significant part of system life cycle costs. The repair costs of a continually aging and complex force of weapon systems become increasingly important with time. Consequently, one of the largest contributors to the high operations and maintenance (O&M) costs is the cost of centralized repair depots within the Air Force Logistics Command (AFLC). The Industrial Systems Directorate, DCS/Maintenance, of AFLC conducted an initial study requested by HQUSAF (LG) on the "Sizing of AFLC Depot Maintenance Facilities" in October 1974. (Ref 9) The study was primarily a historical analysis and included data from five Air Logistic Centers and the Aerospace Guidance and Metrology Center (AGMC) located in Newark, Ohio. The AGMC is a key depot for initial sizing studies since it is relatively small and less complex in scope.

The Aerospace Guidance and Metrology Center is a repair depot responsible for repairing inertial navigation systems for both missiles and aircraft. A centralized repair depot is required for most of the repair work on inertial navigation systems because of the high cost of test equipment, clean room and other specialized resources required. The Air Force Logistics Command is concerned with maintaining costs associated with depots such as AGMC at a minimum level while providing quality repair work on a timely basis.

An economic model of a repair depot was initially developed at AGMC in 1974. (Ref 3) It was designed to estimate total depot costs associated with a given workload. The model contained some inequities, however, and required extensive input tables. Since January 1975 I have met periodically with the analysts at AGMC primarily responsible for the development of a revised model which would have a new and improved approach for analyzing depot costs. It was determined that more accurate methods of estimating direct labor, direct material, facilities and equipment, and overhead costs were required for any given workload. Some method of comparing total costs for each workload was considered necessary which would examine the effects of time and economies of scale. This thesis is intended to help resolve these difficulties.

OBJECTIVES

The objectives of this analysis are as follows:

1. Develop methods of estimating direct labor, direct material, overhead, facilities and equipment costs for a given workload volume and mix of products.

2. Develop an approach for examining and comparing total workload costs from the following viewpoints:

a. If the current workload volume is to be increased (or decreased), which end items, from a given feasible set of end items, should be added (or deleted) which will minimize total workload costs?

b. Given a choice of repairing a product at depot x, depot y or contracting out the repair, what measure of merit in terms of cost should be used for considering such alternatives?

SCOPE AND APPLICATION

This analysis deals with all costs associated with the operation of a repair depot. Workloads are examined for the effects of differing total volume levels and differing combinations of products repaired. While the data and findings are applicable only to the Aerospace Guidance and Metrology Center, the methodology and approach described are generally applicable to other repair depots and related functions. The Metrology Center also located at Newark Air Force Station is excluded from this analysis.

ASSUMPTIONS

The data were closely examined for errors and some corrections

were made. It is assumed that the resulting data base is accurate. All terms and cost category definitions are assumed to have remained unchanged throughout the time period of the data. Excess depot capacity to satisfy surge requirements is not discussed in this analysis. All workloads discussed here are well within depot capacity. It is assumed that surge requirements are satisfied by the unused capacity in terms of equipment and facilities. Lastly, it is assumed that the quality of repair work performed on all end items remains unchanged among all workload alternatives.

DEFINITIONS

Throughout this thesis, the following terms will be used as defined below:

1. Direct Labor Hours or DPAH. Direct labor is generally defined as labor which adds utility to end items being repaired or manufactured and which can be reasonably, consistently and economically identified with such products. (Ref 1; 1) The terms "direct labor hours" and "DPAH" (direct product actual hours) are used interchangeably. In strictly defined terms, DPAH does not represent actual direct labor hours performed. Historical data has not been maintained on actual direct labor hours expended by end item. Rather, DPAH is a revised standard hour figure calculated as follows.

$$DPAH_\alpha = \frac{(U_\alpha)(DPSH_\alpha)}{E}$$

where U_α = number of units of an end item output in month α
$DPSH_\alpha$ = direct product standard hours per unit
E = efficiency factor

The efficiency factor varies over time and is different for each end item. As of December 1974, the efficiency factors for end items in the workload ranged from 0.78 to 1.11. They represent an adjustment for DPSH based upon actual historical performance on each end item. Because of this definition, DPAH is directly tied to DPSH and DPSH was not used in this analysis.

2. Direct Material or Direct Expense Material. Material expended in productive operations where the unit of issue can be reasonably, consistently and economically related to specific end products or jobs. (Ref 1:1)

3. End Item or Product. The object being repaired at the depot. It is referenced in the form in which it enters and leaves the depot, not in any component form which it may take during the repair process. The terms "end item" and "product" are used interchangeably. Specific definitions of each end item are presented in the next chapter.

4. GSAL. An index of average GS level salaries at AGMC by month. The index is corrected for wage increases and is based on average grade levels at AGMC.

5. Military Repair Depot. An organization whose mission is to restore to operating condition faulty weapon systems, subsystems or supporting equipment. (Ref 3:1-1)

6. Overhead. All other costs not classified as direct labor or direct material, except facility and equipment costs. (Ref 1 ; 1) Historical data up through December 1974 breaks overhead into fixed

and variable categories (FOH and VOH) plus a "General and Administrative" category (G&A). For purposes of this study, the fixed overhead and general and administrative expenses have been combined to make up the term "Fixed Overhead." In general terms, fixed and variable overhead are defined as follows:

a. Variable Overhead: Indirect labor and indirect material

b. Fixed Overhead: Operating costs of the staff organizations such as directorate offices, administrative offices, quality control, and resources management. Directorate general expenses are also included, such as office supplies, expendable tools and equipment, utilities, training and facility maintenance. In addition, G&A costs are aggregated into this category and include costs charged for general and administrative type support services provided by base activities. (Ref 1:2)

7. Price Index (PI). The wholesale price index by month, established by the Department of Commerce. In this study, PI provides a means of adjusting for price fluctuations over time.

8. Volume or Units. The number of each type of end item completed and sent out to the user each month. Because of work in process at the end of each month, volume or units do not necessarily identify the number of each end item worked on during a month. "Volume" and "Units" are used interchangeably in this thesis.

CHAPTER 2
WORKLOAD DATA AND STATISTICAL METHODS

SCOPE OF DATA

Data on 18 end items repaired at AGMC are included in Appendix A. Those 18 end items represent approximately 90% of the current (July 1975) AGMC workload. All the data were used to examine general trends and to compute totals by month. However, specific cost relations were not derived for six of the products. Five are relatively new to the workload (since July 1973) and sufficient data points were not available. Historical figures for one item, the G200FG, did not provide satisfactory relations for any cost category. Data on this item requires further detailed study to determine possible changes in definition or methods of accounting for costs.

Data going back as far as July 1963 were used in the study of direct labor. In all other cost categories, the period from July 1972 through June 1974 was studied. When the figures were available and considered accurate, the July - December 1974 statistics were also used to provide a more current data base. However, since January 1975, record keeping procedures have changed somewhat to comply with a new system called MINIMAX. For example, actual direct labor hours are now recorded rather than revised standard hours which DPAH represents in this study. Because of these changes, data since December 1974 are not directly compatible with previous data. This point must be kept in mind when subsequent studies are conducted.

The historical data were closely examined for errors. When discrepancies were found, the erroneous values were corrected if possible or otherwise deleted from the data base. Such deletions are identified in Appendix A by a dash (-). If a blank space appears in any month for an end item, then the item was not in the workload during that month.

All statistics were gathered from one of three sources. Background data on direct labor and units prior to July 1972 were taken from AFLC Form 543A-4 (LOG K-332 Report). Data for the period July 1972 through June 1974 are from the AGMC G072 Report. Corresponding figures for the July - December 1974 period were acquired from the F307582 report (WIP account by Project Order).

DESCRIPTION OF END ITEMS

The description and applicable weapon system for each end item in this analysis are listed below.

TABLE I
Description of End Items

End Item	Weapon System	Description
LN-12	F-4	Platform
NS-10	MMI(Safeguard)	Missile Guidance Set
LGM-25	TITAN	Missile Guidance Set
NS-17	MMII	Missile Guidance Set
LN-14	F - 111	Platform
LN-7	RC-135	Platform
NS-20	MMIII	Missile Guidance Set
C5-A	C5-A	Inertial Measurement Unit
N-16	F-111	Inertial Reference Unit
KT-71	F-105	Inertial Measurement Unit

continued

TABLE I (continued)
Description of End Items

End Item	Weapon System	Description
KT-73	A-7	Inertial Measurement Unit
N-16GY	F-111	Gyroscope
SR-3	F-111	Displacement Gyroscope
7900D	C5-A	Displacement Gyroscope
T-38	T-38, F-4	Displacement Gyroscope
2171AB	F-4, AC-130, T-43, F-105, AC-119	Displacement Gyroscope
2171W	F-105, F-106	Displacement Gyroscope
G200FG	F-4	Gyroscope

STATISTICAL APPROACH

For each cost category of direct labor, direct material, variable overhead and fixed overhead, historical data are examined for general trends and possible relationships to independent variables. Hypotheses are made concerning the general form of a relation which would explain variations in each category. Ordinary Least Squares and Generalized Least Squares techniques are applied, based on the hypothesized relations, and then corrected for inaccuracies. Basic economic theory is then used to discuss approaches to workload analysis. Some basic theory on linear models and least squares will now be briefly discussed. The primary sources used for these techniques were Theil (Ref 10: Chap 3, 6, 7), and Mendenhall and Schaeffer (Ref 5: Chap 11).

NOTATION

In vector/matrix notation, capital letters refer to vectors or matrices and subscripted lower case letters refer to elements of a vector or matrix. A hat over a variable or parameter ($\hat{Y}$) indicates an estimate or prediction. The letter y designates the dependent variable and x an independent variable.

The transpose of a matrix is indicated by an apostrophe. For example, X' is the transpose of X. An exponent of (-1) refers to the inverse of a matrix. For example, X^{-1} is the inverse of X. B_0 represents a constant and B_1, $B_2 \cdots B_k$ designate coefficients of K independent variables. The letter E refers to the estimation error or residual.

LINEAR MODEL

The linear model relates a dependent variable to a linear function of independent variables. In proper notation, the model takes the following form:

$$Y = XB + E$$

where B is a vector or unknown coefficients and the expected value of E is zero. In applying n observations of data to this equation:

$$Y = \begin{bmatrix} Y_1 \\ Y_2 \\ \cdot \\ \cdot \\ \cdot \\ Y_n \end{bmatrix} \qquad X = \begin{bmatrix} 1X_{11} & X_{12} & \ldots X_{1k} \\ 1X_{21} & X_{22} & \ldots X_{2k} \\ \cdot\ \cdot & \cdot & \cdot \\ \cdot\ \cdot & \cdot & \cdot \\ \cdot\ \cdot & \cdot & \cdot \\ 1\,X_{n1} & X_{n2} & \ldots X_{nk} \end{bmatrix} \qquad B = \begin{bmatrix} B_0 \\ B_1 \\ \cdot \\ \cdot \\ \cdot \\ B_k \end{bmatrix} \qquad E = \begin{bmatrix} e_1 \\ e_2 \\ \cdot \\ \cdot \\ \cdot \\ e_n \end{bmatrix}$$

ORDINARY LEAST SQUARES

Least Squares is a method of fitting a linear function of variables to a set of actual observations of a dependent variable to find estimates for the coefficients (B). Once the coefficients have been estimated, the linear model takes the form:

$$\hat{Y} = X\hat{B}$$

The Least Squares method minimizes the sum of squared deviations of components of the observed and estimated response vectors. The estimated vector of coefficients is given by:

$$\hat{B} = (X'X)^{-1} X'Y$$

The assumptions underlying the least squares technique are as follows:

1. The observed elements of the Y vector and X matrix are measured without error.

2. The error vector E is normally distributed.

3. The conditional mean vector of E , given X, is

$$E\,(E \mid X) = 0$$

4. The variance/covariance matrix of Y, given X, is

$$\mathrm{Var}\,(Y \mid X) = \sigma^2 I$$

where σ^2 is an unknown positive parameter and I is the nXn identity matrix.

Based on these assumptions, the least squares estimates have the following properties:

1. The estimated coefficients are unbiased, i.e.,

$$E(\hat{B}) = B$$

2. The variance/covariance matrix for the estimated coefficients is given by

$$\text{Var}(\hat{B}) = \sigma^2 (X'X)^{-1}$$

3. The elements of $\hat{B}$ are each normally distributed.

4. The unbiased estimator for σ^2, denoted S^2, is

$$S^2 = \frac{(Y - \hat{Y})' (Y - \hat{Y})}{n - K}$$

Some Generalized Least Squares techniques were applied when correcting for deficiencies in the ordinary least squares results. The procedures used will be discussed as they are applied in the following chapter.

VALIDATION

After relationships are derived, it is important to examine how close the estimated values come to actual values not considered in the data base. However, using multivariate regression it is difficult to find more than one or two data points with the same combination of independent variable values as those used in the estimator. All variables must be held constant except one to determine the marginal effect of that one variable. In examining the effect of each variable, the remaining variables were held constant at a value equal to the actual May 1975 value so that the actual figure could be compared to estimates. May 1975 was chosen because it is a recent period but

not the last month in the fiscal year.

The estimation of direct labor hours is critical for the entire analysis of workload costs and will be discussed first.

CHAPTER 3
DIRECT LABOR

INTRODUCTION

The estimation of direct labor costs for a given workload is probably the most critical and certainly one of the most difficult to derive in the production process. The sole use of regression techniques to derive a direct labor cost function for use on all potential workloads is not a realistic or accurate approach. While historical direct labor costs do provide valuable information for future predictions, they must be considered in light of other significant factors. Some of the other factors which must be considered include:

1. The range of volume levels, future workload versus past workload
2. Experience level of workers on a specific product
3. Level of technology
4. Changes in the type or extent of repair on a specific product
5. Workload capacity -- overtime, time limits on output, economies of scale
6. Lag time between changes in volume level and corresponding changes in available manpower

Others could be added to this list. Furthermore, when a new product is added to the workload, the problem of finding an existing product which resembles the new one in terms of labor requirements becomes critical. Or, if no product resembles the new one, what cost function should be

applied for the most accurate results? In some cases, good judgement and common sense will provide the best answers to these troublesome questions.

HYPOTHESIS

A good starting point is to form hypotheses about what happens to direct labor hours per unit of production as volume changes and as time changes. The hypothetical statements and analyses are made in terms of direct labor hours. Hours will be converted to costs at a later point.

It is reasonable to hypothesize that direct labor hours per unit of some item (DPAH/U) over time would move as indicated in Figure 1, assuming no significant changes in the type of work performed on the

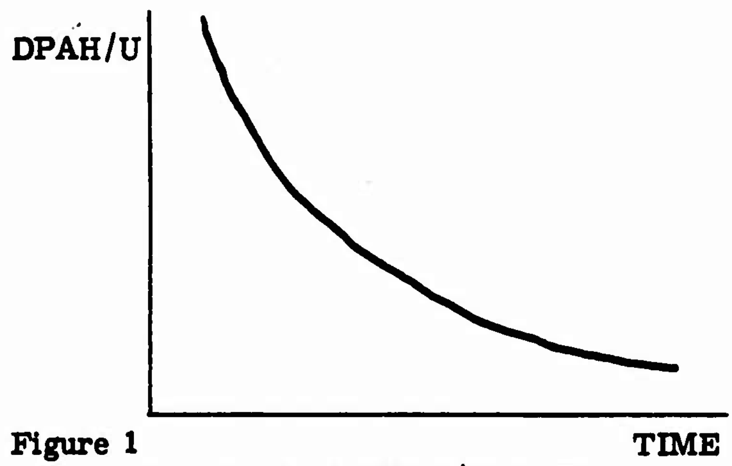


Figure 1
Hypothesized DPAH/U Vs Time

item and assuming no major drop in volume after resources have been built up to a relatively constant operating level. This plot reflects lack of familiarity with the item, lack of efficiently operating repair lines and relatively low volume levels in the initial periods of the

product's history. As time progresses, workers gain experience, repair lines become more efficient, and volume level picks up such that the same number of workers can produce (repair) an increasing number of end items. However, if volume level later drops significantly, such as in a phase-out period, the curve could slope upward again, indicating idle manpower (Figure 2a). A major change in the type or extent of work performed on an item could also cause an upward slope or hump in the curve over time (Figure 2b).

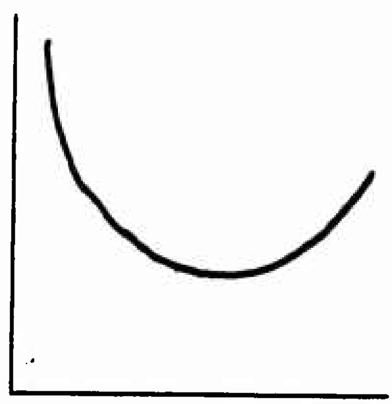


Figure 2a
Reduced Volume Effects

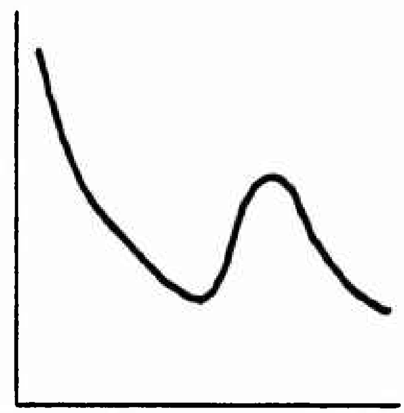


Figure 2b
Effects of Major Changes in Repair

The slope of the curve in Figure 1 depends in part on the degree to which the item resembles an item previously in the workload. In cases where a resemblance among products exists, an existing repair line may be used along with labor already familiar with the type of repair required, resulting in a relatively steep slope.

It also seems reasonable to hypothesize that the plot of direct labor hours per unit against volume would take on a somewhat similar shape as Figure 1 if time is identified for each point (Figure 3).

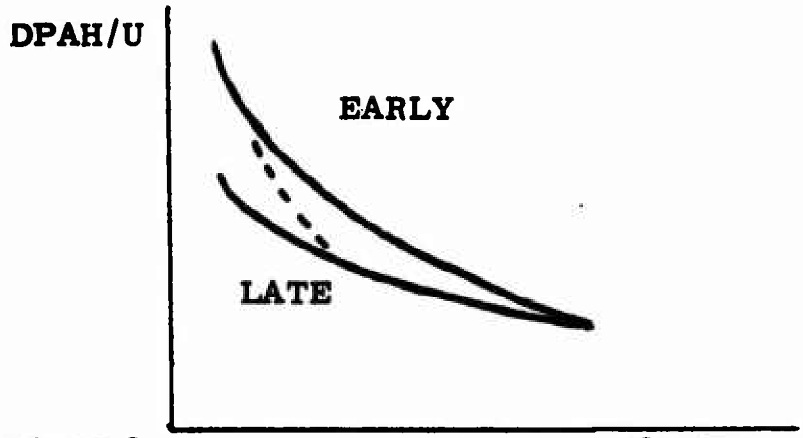


Figure 3
Hypothesized DPAH/U Vs Volume

Here, the negative slope reflects improved utilization of available labor as volume increases, assuming capacity has not been reached. In addition, efficiency of workers would tend to improve as volume picks up and more products are handled. If volume drops later in the life cycle of an end item, however, the utilization of labor far below capacity would tend to push DPAH/U back up again. The benefit of experience with the end item still remains and may keep the DPAH/U below that previously recorded for the same volume level in earlier periods. The difference between the early and late curves, then, is some indication of the learning effect. If the idle labor in later periods due to decreased volume is severe enough, however, that cost may eliminate any benefit of experience, and the early and late portions of the curve could be essentially the same in terms of direct labor hours per unit (dotted line).

The approach in direct labor, then, will be to examine such graphs for each end item covered in this analysis. If there does appear to be some similarity between items, then the DPAH/U can be normalized over all units and we can meaningfully describe the general trend. If a "normal operating range" can be identified for each end item, then it is worthwhile to use regression techniques to derive direct labor functions for each item to use over the specific operating range identified.

DIRECT LABOR FUNCTIONS IN GENERAL

The actual graphs of direct labor per unit versus volume are attached for the 12 end items involved in this analysis which had a significant number of data points (Appendix B). The NS10 is also depicted over time and will be discussed later.

By examining the labor requirements per unit over time for each item, it appears that DPAH/Unit is relatively sporadic in the initial time periods. However, as time goes on, nearly all the items appear to enter a period where DPAH/U gradually falls, then begins to level out. Work in process at the end of each month accounts for at least some of the fluctuation from month to month. The "units" used to depict volume level in these graphs are the units output during each given month. The DPAH are direct labor hours recorded during each month, some of which may have been expended on units still in work at the end of month. Consequently, DPAH/U may be excessively high

in one month, then drop to an excessively low point the following month. This fluctuation is accounted for in the relations derived later for direct labor.

A clearer comparison could be made if we overlaid the plot of each item over the other to find similar trends starting when each item entered the workload. While time is in terms common to all items, DPAH/U should be "normalized" so that all items can be plotted on a scale meaningful for comparison. In Figures 4 and 5, DPAH/Unit has been normalized over the first 24 months and second 24 months of life for five end items. That is, direct labor hours per unit were divided by the 24-month average for each item to put all data points on a comparable scale. In arriving at the 24-month figure, I examined the individual graphs to get an estimate of how long the initial "sporadic" phase lasted before direct labor requirements began to follow the hypothesized trend. While some took more and some less, it appears that the first two years of production takes in most of the initial fluctuation in DPAH/Unit. Time does not represent any specific date for all items in these Figures. Time period 1 represents the first month of repair for each item in the AGMC workload. The first month is July 1963 in one case and November 1969 in another. The important point here is to examine labor performance among products at their same experience level in the depot.

Direct labor requirements gradually appear to decline during the first period and more so in the second. However, volume level also

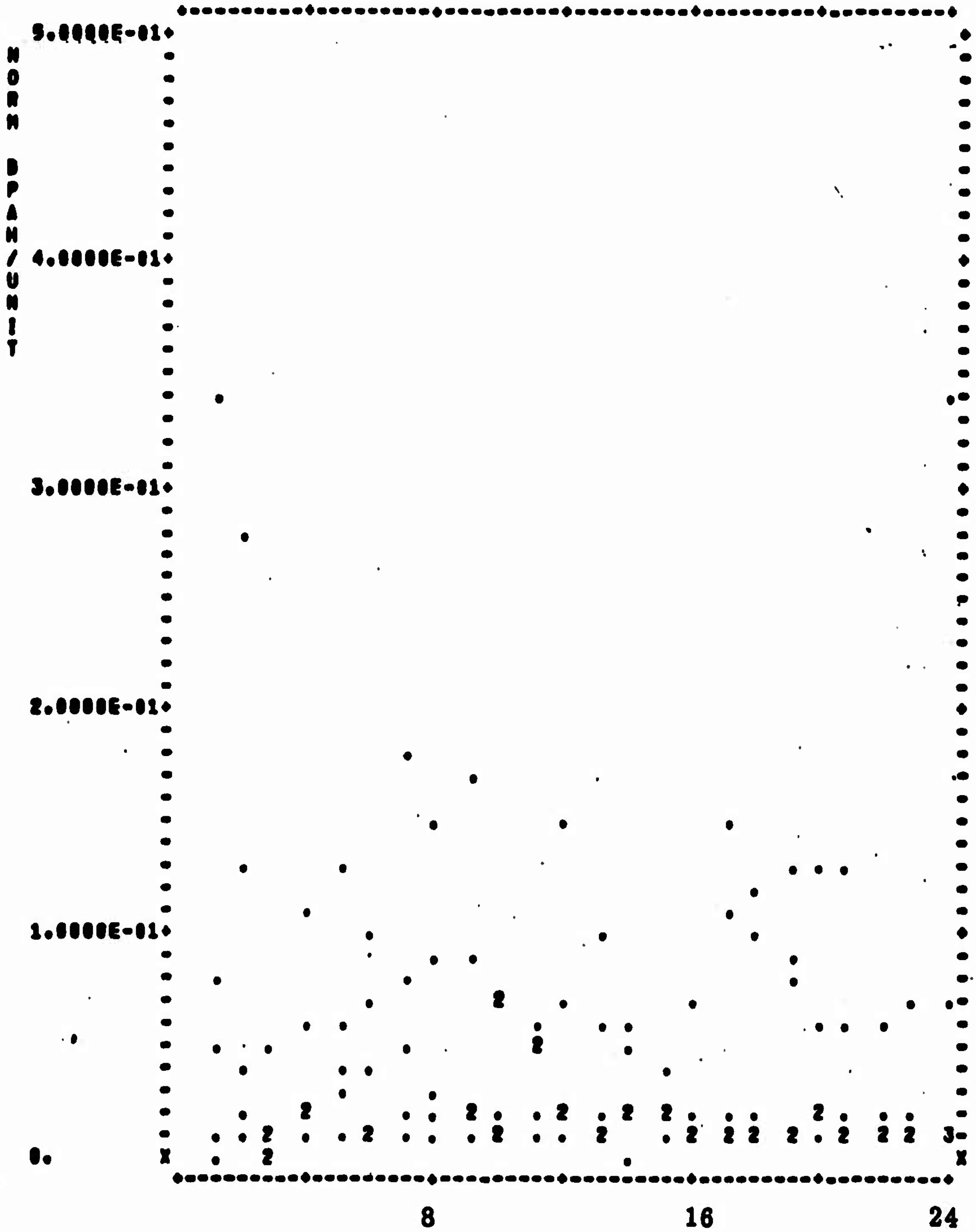


Figure 4
Normalized DPAH/U vs Time-1st 24 Months

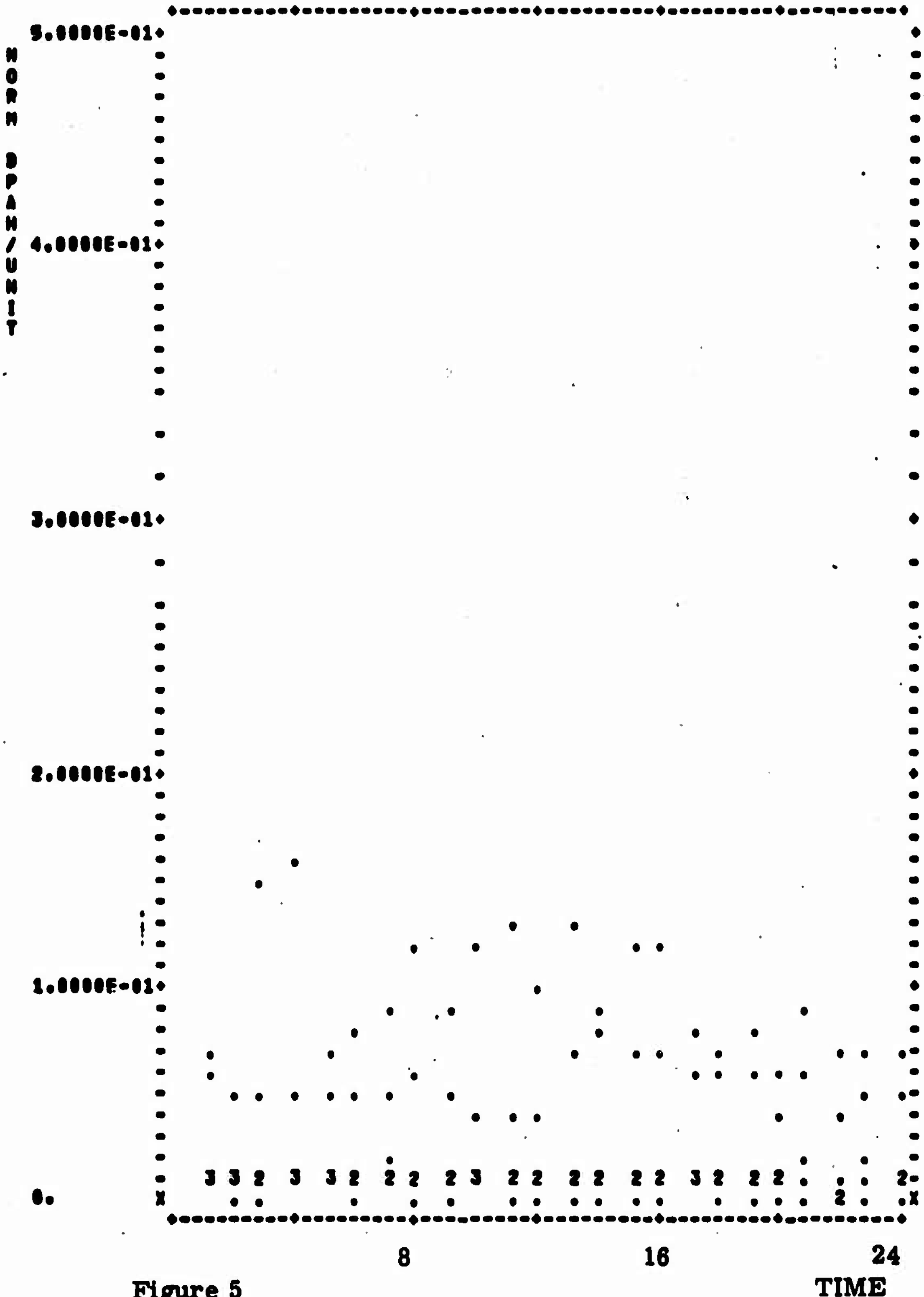


Figure 5
Normalized DPAH/U vs Time-2nd 24 Months

fluctuates over time in this graph and tends to hide the total effect of time. The individual effects of time and volume will be discussed later with regard to specific products.

In a similar fashion, normalized direct labor hours per unit are plotted against volume in Figures 6 and 7. Here, a much more definite trend is evident which supports the hypothesized effect of volume on direct labor. Again, however, time is not constant in this plot and its effects are mixed in with those of volume.

The relationship of time and volume to direct labor hours will vary from product to product. For that reason, specific functions are derived and explained in a later section for individual end items. Before discussing those, the rationale for choosing variables and the functional forms will be discussed, as well as the criteria for choosing the "best" relationship.

RATIONALE AND CRITERIA FOR DIRECT LABOR FUNCTIONS

The estimation of direct labor is based on the initial hypothesis that direct labor hours in month α are a function of four independent variables: Units produced (output) in month α, units produced in month $\alpha+1$, time$_\alpha$ and time$_\alpha$ squared. The selection of variables was based simply on reason and a cursory examination of the direct labor trends in Appendix B.

Because of the increased experience and learning curve effects over time, DPAH is expected to decrease relative to increases in time if volume is held constant. It is not clear, however, that this

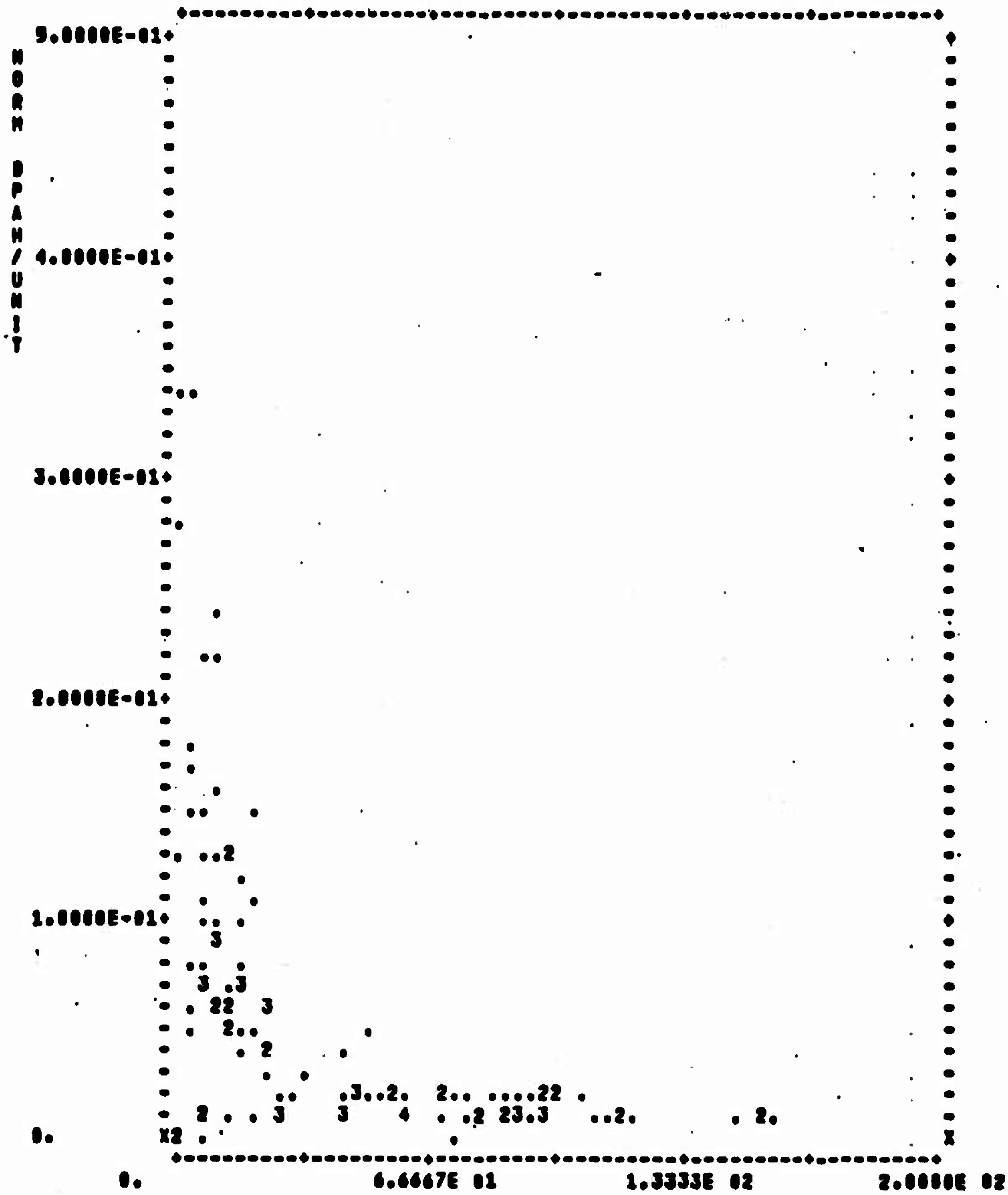


Figure 6

Normalized DPAH/U vs Units-1st 24 Months

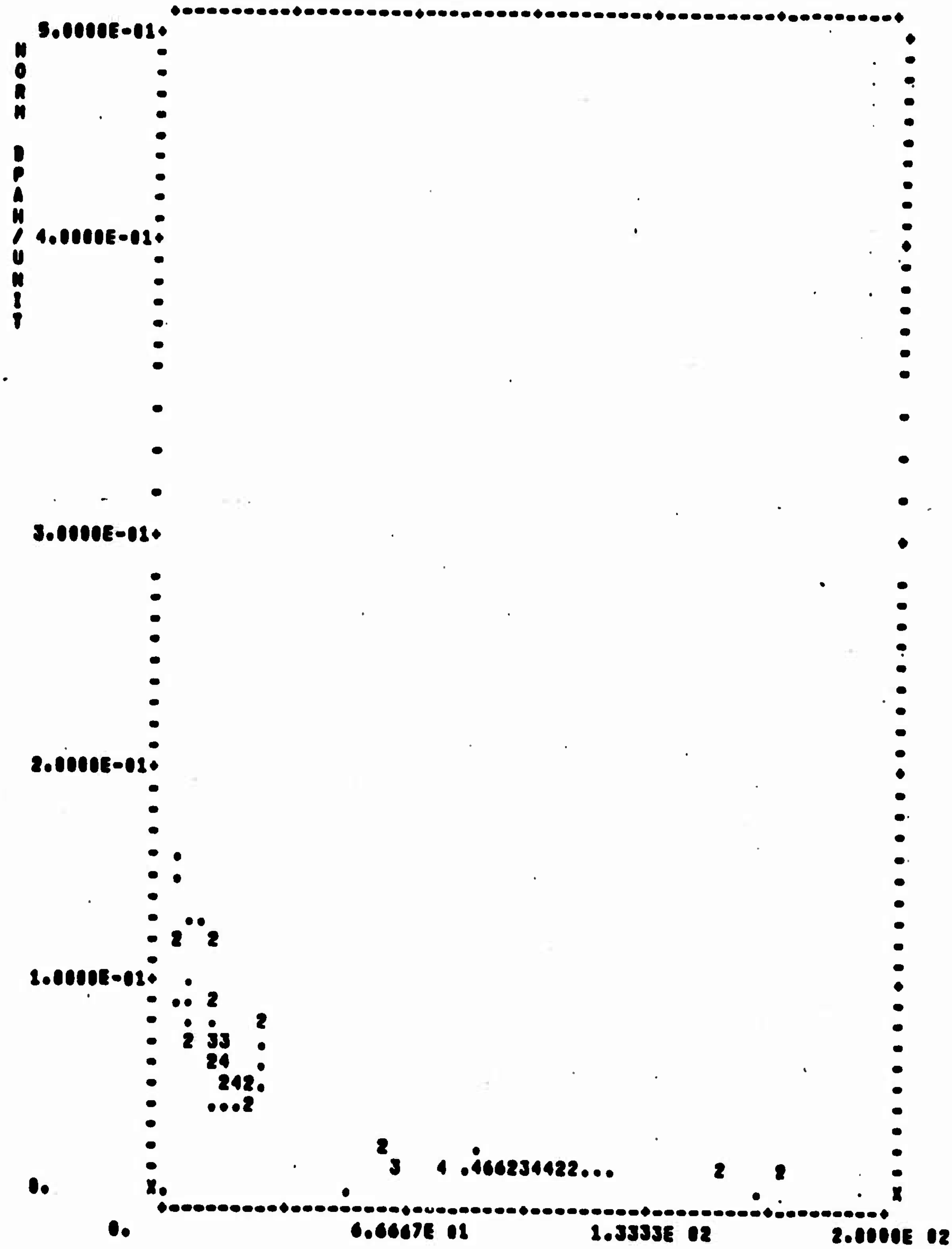


Figure 7 UNITS

Normalized DPAH/U vs Units-2nd 24 Months

relationship is linear. Therefore, a squared time variable is included in the hypothesized relationship. DPAH should also decrease relative to increases in units produced, assuming the depot is not operating at capacity. Greater numbers of units will tend to make greater use of available labor and higher volume should tend to increase labor productivity if capacity has not been reached. A variable representing units produced in month $\alpha + 1$ is initially entered as a relevant variable to account for work in process at the end of each month.

There are several criteria for deciding upon a good relationship between DPAH and these variables. One of the most important conditions is that the relationship must agree with common sense. If it does not seem reasonable that a variable would answer some of the variance of the dependent variable, then it should not be a part of the hypothesized relationship. If the variables are reasonable, the relationship must then be able to predict the dependent variable with reasonable accuracy. A test of validity will be discussed in conjunction with the specific product functions. It must then be determined whether each variable is a significant contributor in explaining direct labor hours. To determine significance, the t ratio

$$t_b = \frac{b}{s_b} = \frac{\text{Variable Coefficient}}{\text{Std Dev of Coefficient}}$$

was applied to a table of t statistics. Generally, if the t ratio represented a value greater than or equal to 2.0, the coefficient was determined to be significantly different from zero. (Ref 7:47)

After dropping insignificant variables from the relationship for each end item, several different forms of relationships were examined, using R^2 as the primary criteria for determining the most accurate form of the equation to use. R^2, or coefficient of determination, is defined as follows: (Ref 7: 44)

$$R^2 = \frac{\text{Explained Variance}}{\text{Total Variance}}$$

An R^2 of 1.0, for example, would indicate that all observed points lie on the regression line.

Among the forms of relations attempted were:

$$\widehat{DPAH_\alpha} = B_0 + B_1(U_\alpha) + B_2(U_{\alpha+1}) + B_3(Time_\alpha) + B_4(Time_\alpha)^2$$

$$\widehat{\frac{DPAH_\alpha}{Unit_\alpha}} = B_0 + B_1(U_\alpha) + B_2(U_{\alpha+1}) + B_3(Time_\alpha) + B_4(Time_\alpha)^2$$

$$\widehat{\frac{DPAH_\alpha}{Unit_\alpha}} = U_\alpha * e^{-Bt_\alpha}$$

$$\widehat{\ln(DPAH_\alpha)} = B_0 + B_1\ln(U_\alpha) + B_2\ln(U_{\alpha+1}) + B_3\ln(Time_\alpha) + B_4\ln(Time_\alpha)^2$$

The first form listed consistently provided the highest R^2 for all end items.

The use of different data sets was also considered. Based on the earlier discussion of sporadic direct labor requirements during the initial phase of the life of a product repaired at the depot, it would appear reasonable that R^2 could be significantly improved by dropping the initial periods of repair and focusing on the normal operating periods. This proposal was attempted but subsequently dropped for two reasons. First, R^2 was not significantly improved by deleting the

first 24 months of the life of an end item. Second, if the initial phase was not included in deriving a relation for a product, the resulting relation would not be useful in explaining direct labor requirements during the early months of repair. Consequently, data on the full life of each end item were utilized up through June 1974 in arriving at direct labor functions for each of the 12 products.

It is possible that a time lag exists between large changes in volume level and corresponding changes in direct labor hours. If LGM25 volume level dropped, for example, because of a reduction in TITAN weapon systems from the inventory, it may take some time to move manpower from the LGM25 repair to some other type ot work. In this light, several correlation tests were made to determine if volume level in any given time period was more closely correlated with labor hours at a later period. Time lags of 3 months, 6 months, and 1 year were tested. While a time lag may exist, the correlation tests did not identify a consistent lag which improved the relationship of labor hours to volume level. The closer relationship existed between DPAH in period α to volume in period α than for any lag period tested. Consequently, the $\text{units}_{\alpha+1}$ variable was the only one used to consider subsequent time periods. The $\text{units}_{\alpha+1}$ variable was primarily used to account for work-in-process.

DERIVATION OF DIRECT LABOR FUNCTIONS BY END ITEM

The 18 products considered in this study represent approximately 90% of the depot workload as of FY75. Specific functions were not

derived for six of the 18 which are relatively new to the workload and had less than 10 data points. Multivariate least squares regression techniques were applied to each data set, initially using a constant and four independent variables as discussed earlier. Variables were subsequently deleted in each case where the t statistics indicated insignificance. All data sets were examined for indications of multicollinearity, heteroscedasticity and autocorrelation. The resulting equations, after appropriate corrections, were then tested for validity and predictability. While this procedure was performed for each of the 12 end items, one major end item, the LN12, will be discussed here in detail to clarify the approach.

The initial version of the regression model took the following form:

$$DPAH_{\alpha} = f(C,\ U_{\alpha},\ U_{\alpha+1},\ T_{\alpha},\ T_{\alpha}^{2})$$

where: α = Month, going from 1 to 108 in the case of LN12 (i.e., repair of the LN12 began in July 65 or 108 months prior to most recent data point)
C = Constant
U = Number of units produced in a month (output)
T = Time, expressed as a consecutive integer from 1 to n, the number of months considered for the item

In the case of LN12, the t statistic for the $U_{\alpha+1}$ variable was -1.3 which did not support the hypothesis that the coefficient for that variable was significantly different from zero. The $U_{\alpha+1}$ variable was dropped and the remaining variables were left with t statistics of 5.41, 3.85, 5.31, and -6.14 for C, U_{α}, T_{α}, and T_{α}^{2} respectively which indicate significance. The F statistics for joint and conditional significance of coefficients were examined and showed similar results.

The F statistic is defined as follows: (Ref 7: 69)

$$F = \frac{\text{Increment of explained Variance} \div \text{Degrees of Freedom}}{\text{Remaining unexplained Variance} \div \text{Degrees of Freedom}}$$

For example, the F statistic for the third of 4 variables is defined as:

$$\frac{\text{Reduction in sum of squared residuals due to 4th var}}{\text{Residual Variance}}$$

This statistic indicates the significance of one variable, given that the effects of subsequent variables have been subtracted out. The representative F statistics for the LN12 were 4851.7, 366.3, 42.1, and 37.7 for C, U_α, T_α, and $T_\alpha^{\ 2}$ respectively. All show definite signs of significance when the effects of subsequent variables have been subtracted out.

The coefficient of determination adjusted for degrees of freedom ($\bar{R}^2$) was .81 for the following LN12 function:

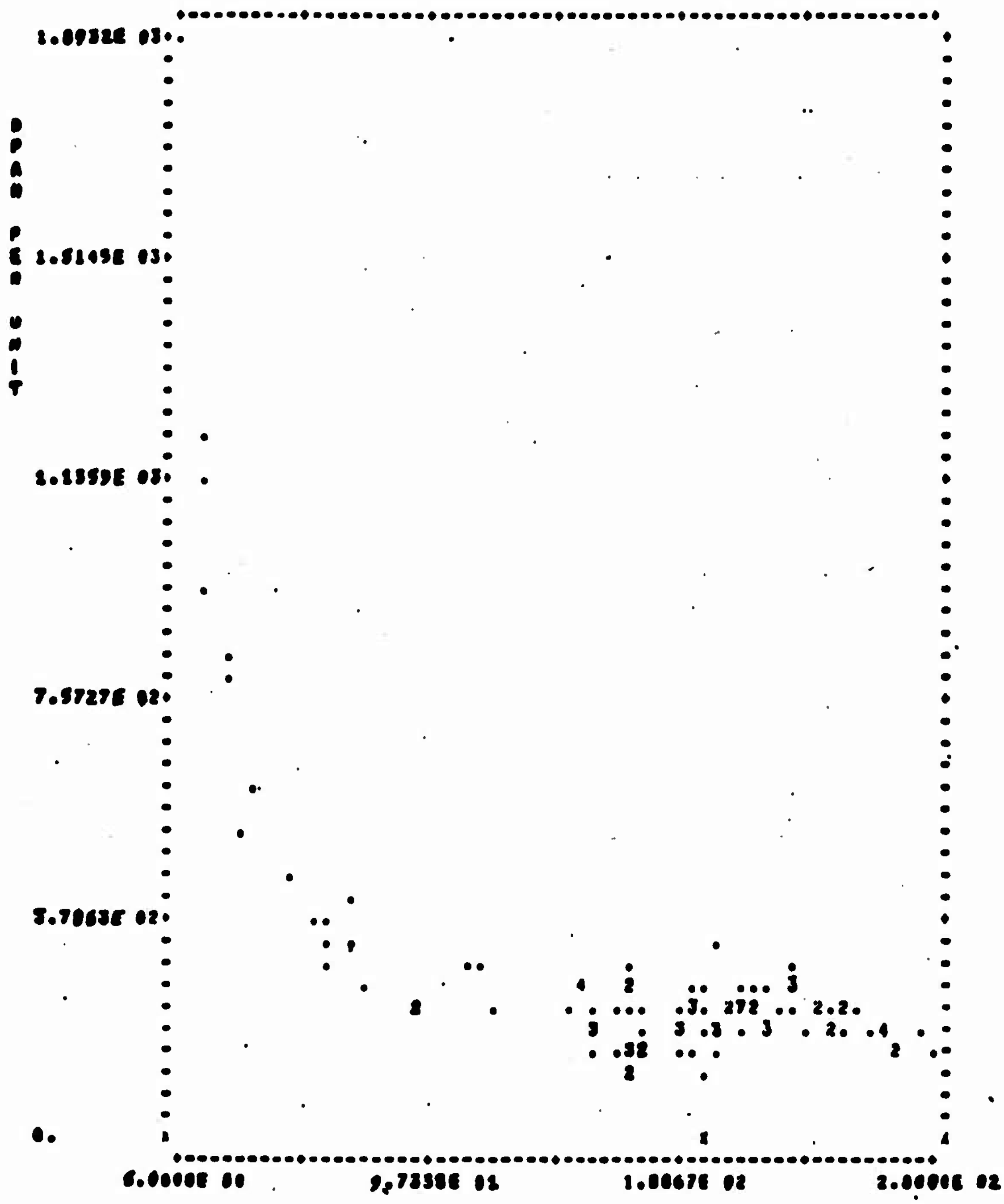
$$DPAH_\alpha = 9420.6 + 77.3\ U_\alpha + 912.9\ T_\alpha - 8.6\ T_\alpha^{\ 2}$$

The signs of the coefficients deserve close examination. The relation suggests that direct labor requirements increase as volume rises but are affected more by time as indicated by the magnitude of each coefficient. However, as time goes on, the time squared variable becomes a major factor and offsets the impact of the unit and time variables to some degree. This lends some support to the hypothesis that DPAH/U will generally begin to decrease at some point over time. However, it does not imply that the decrease begins immediately as hypothesized in Figure 1.

Figures 8 and 9 show what has actually happened to LN12 DPAH/U as volume increased and as time proceeded. Both support the trends identified in Figures 1 and 4. Again, however, each figure contains both the effects of time and volume to some extent in that both variables are fluctuating. The relation derived for the LN12 was used to examine the separate effects of time and volume. First, however, the function was examined for possible inaccuracies.

MULTICOLLINEARITY

While the results of the final model appear favorable for the LN12 in terms of explaining the dependent variable ($\bar{R}^2 = .81$), it is possible that one or more of the independent variables are highly correlated with others. In such a case, we are unable to break out the separate effects of each variable on the dependent variable and a multicollinearity problem exists. To test for this condition, regressions were run using each independent variable as the dependent variable and fitting each against the remaining independent variables to find R^2. (Ref 10: 147) A high R^2 would indicate multicollinearity and one of the correlated variables would have to be dropped from the equation. Since there are only two basic variables in the relation that must be examined separately, time and volume, only one R^2 was required. In the case of the LN12, the R^2 for time versus volume was .22 which does not indicate a multicollinearity problem. The corresponding test conducted on other end items also resulted in low R^2 between independent variables.



UNITS

Figure 8

DPAH/U vs Units (LN-12)

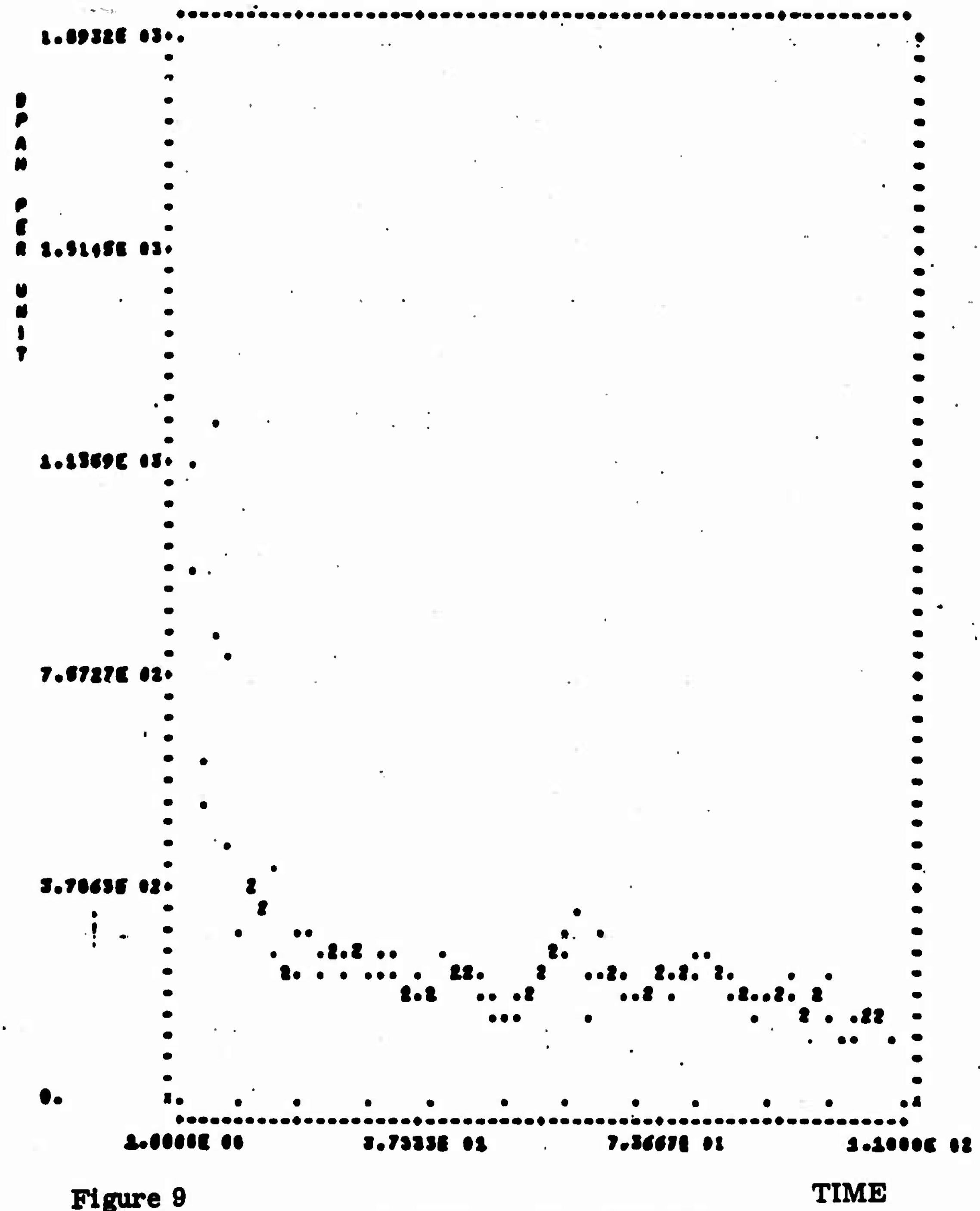


Figure 9

DPAH/U vs Time (LN-12)

AUTOCORRELATION

The regression program developed for use on each end item included the computation of a Durbin-Watson test statistic (d) for autocorrelation. This problem can occur in time series related data and represents a dependence of one observation upon another observation over time. With the existence of autocorrelation, we may tend to conclude that a variable is significantly reducing variations in DPAH when in reality it is not. The test used in this analysis for autocorrelation is described by Theil and outlined below: (Ref 10: Chap 5 and 6)

H_O: No positive autocorrelation
H_A: Positive autocorrelation

At 1% confidence, upper and lower bounds are:

$\left.\begin{array}{l} d_u = 1.6 \\ d_l = 1.48 \end{array}\right\}$ From a Durbin-Watson table for K=4, n=108 as in LN12 case. K = #of independent var
n = #of observations

$$\hat{d} = \frac{\sum_{\alpha=1}^{n-1} (e_{\alpha+1} - e_{\alpha})^2}{\sum_{\alpha=1}^{n} e_{\alpha}^2}$$

where: α = observation #
e = residual $(y - \hat{y})$

If $\hat{d} > d_u$, Accept H_O
If $d_l \leq \hat{d} \leq d_u$, No conclusion
If $\hat{d} < d_l$, Reject H_O

The same test using $4-\hat{d}$ rather than $\hat{d}$ was used to detect negative autocorrelation. For the LN12, $\hat{d}$ = 1.12 which was less than d_l. Therefore, a positive autocorrelation problem existed. The problem did exist for 5 of the 12 end items. A Generalized Least Squares correction procedure is outlined in Theil that was used to correct those equations

requiring it. (Ref 10: 253) Briefly, the observations are transformed as follows:

For the first observation, y_1 becomes

$$y_1 \sqrt{1 - \rho^2}$$

For the n-1 other observations, y_α becomes

$$y_\alpha - \rho\, y_{\alpha-1}$$

where: $$\hat{\rho} = \frac{\sum_{\alpha=1}^{n-1} e_\alpha\, e_{\alpha+1}}{(n-1)\, s^2}$$

In these transformations, $\hat{\rho}$ serves as the estimate of the correlation coefficient of successive error terms and e is the error term.

The same transformation process is applied to each independent variable and constant that may exist in the relation.

HETEROSCEDASTICITY

The weakest assumption of the Least Squares regression model was then examined - that the diagonal elements of the variance/co-variance matrix are equal, i.e., Var (E) = σ^2 I. When the diagonal elements are not equal, then a basic assumption is violated and the problem known as Heteroscedasticity exists. One indication of such a problem is a tendency for the variance of standardized residuals to increase as one of the independent variables increases. A more specific test utilizes an F statistic and is described by Theil among others. (Ref 10: Chap 5 and 6) The LN12 case did have heterosce-dasticity with regard to the units variable. The increasing variance in standardized residuals as volume increased is evident in Figure 10.

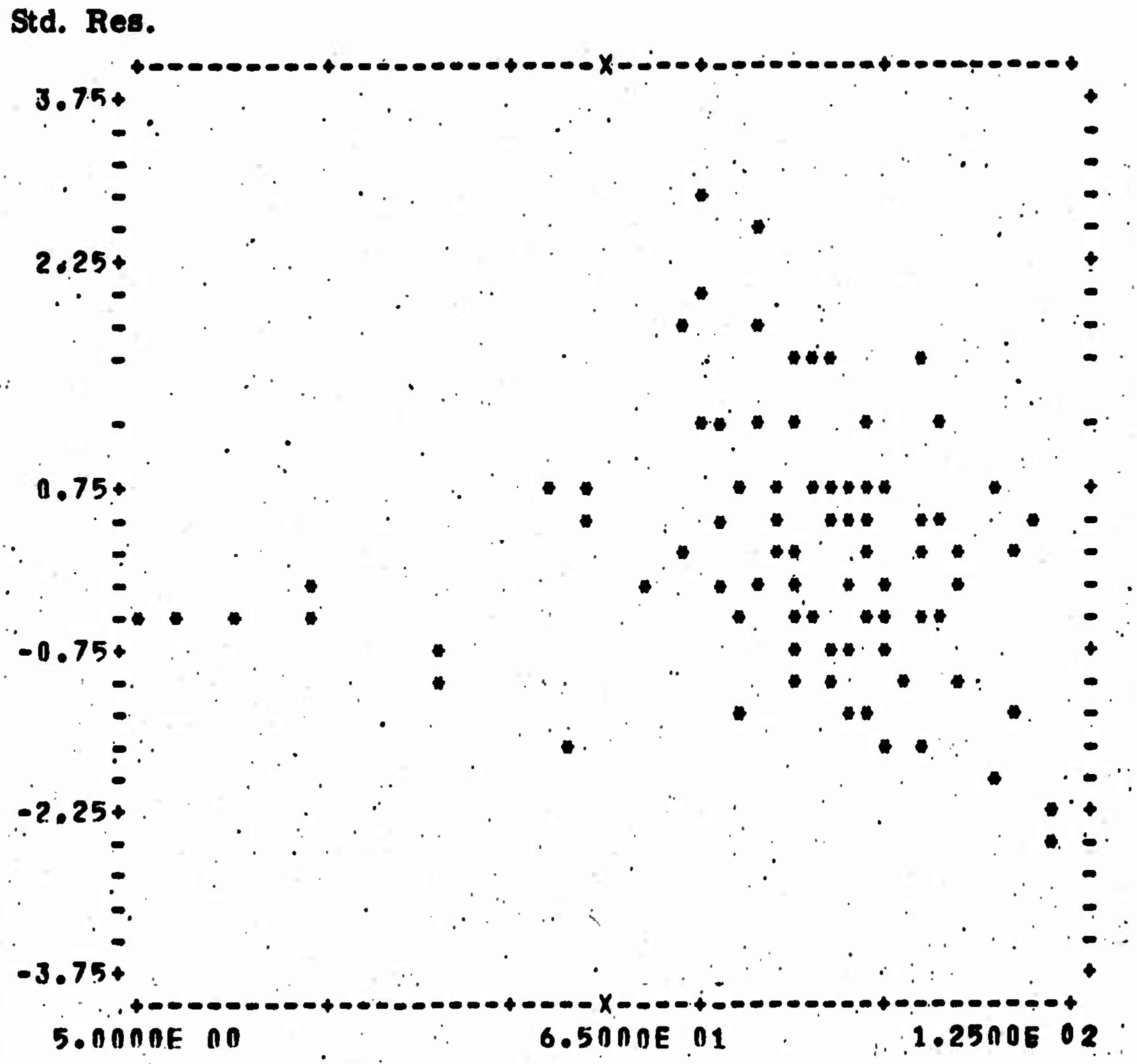


Figure 10

Standardized Residuals Vs. Volume

Of the 12 items tested, seven had indications of heteroscedasticity connected with the units variable. Correction for this problem amounts to weighting each factor in the regression equation by the suspect variable. In the LN12 case, the equation took the following form for correction purposes:

$$\frac{DPAH_a}{U_a} = \frac{B_0}{U_a} + B_1 + \frac{B_2\,U_{a+1}}{U_a} + \frac{B_3\,T_a}{U_a} + \frac{B_4\,T_a^2}{U_a} + \frac{E_a}{U_a}$$

After adjustments, the LN12 relation took the following form: (See Table II for all end items)

$$DPAH = 9091.47 + 73.34\ U + 953.48\ T - 8.96T^2$$

VALIDATION

Once the functions are derived and corrected where necessary, it is important to test for validity and specify the upper and lower bounds for predicted values in terms of a confidence interval. It is also important to conduct sensitivity analysis on the marginal effects of each independent variable upon direct labor requirements.

Figure 11 is a plot of the LN12 predicted values over time at specified, fixed volume levels. The initial rise in DPAH/U and subsequent fall discussed earlier is obvious in this graph where the effects of fluctuating volume levels have been eliminated. A volume of 200 units is the approximate normal level for LN12. Upper and lower extremes of 100 and 300 units are also plotted. The direct labor requirements per unit are less as volume reaches higher levels and the variation in requirements over time is less for higher volume levels. These results are based on activity levels which are within depot capacity.

Assuming an average volume level of 200 units, Figure 12 identifies the estimated DPAH/U values over time and the one-standard deviation (approximately 70%) confidence limits for those values. A validity test for the LN12 relation was conducted by

TABLE II
DPAH COEFFICIENTS

End Item	R^2		Constant	Variables				Adj*
				$Unit_a$	$Unit_{a+1}$	$Time_a$	$Time_a^2$	
LN-12	.81	COEFF	9091.47	73.34		953.48	-8.96	1,2
		STD DEV	1724.77	20.76		180.14	1.48	
NS-10	.73	COEFF	33940.17	200.57	263.96	-670.37	3.24	
		STD DEV	6634.21	78.61	80.66	123.41	1.02	
LGM-25	.53	COEFF	9163.34	577.32	309.18	-163.62	.91	2
		STD DEV	1738.99	122.73	126.56	41.73	.31	
NS-17	.77	COEFF		270.32		959.58	-9.82	1,2
		STD DEV		24.90		119.10	1.27	
LN-14	.78	COEFF		151.77		33.01		1,2
		STD DEV		23.14		11.64		
LN-7	.34	COEFF		253.09		12.34	-.21	
		STD DEV		36.89		3.59	.06	
NS-20	.88	COEFF		119.29		201.93		1
		STD DEV		35.46		30.64		
C5-A	.80	COEFF		137.45		166.63	-1.76	2
		STD DEV		37.34		36.25	.73	
N-16	.75	COEFF				122.14	-1.59	
		STD DEV				13.11	.44	
KT-71	.71	COEFF		199.09		57.91	-1.85	2
		STD DEV		18.49		14.47	.43	
KT-73	.73	COEFF		73.90		558.89	-15.81	1
		STD DEV		48.59		161.16	4.11	
N-16GY	.55	COEFF		47.96		117.49	-3.93	
		STD DEV		9.06		23.03	.66	

*ADJ: 1=Corrected for Autocorrelation
2=Corrected for Heteroscedasticity

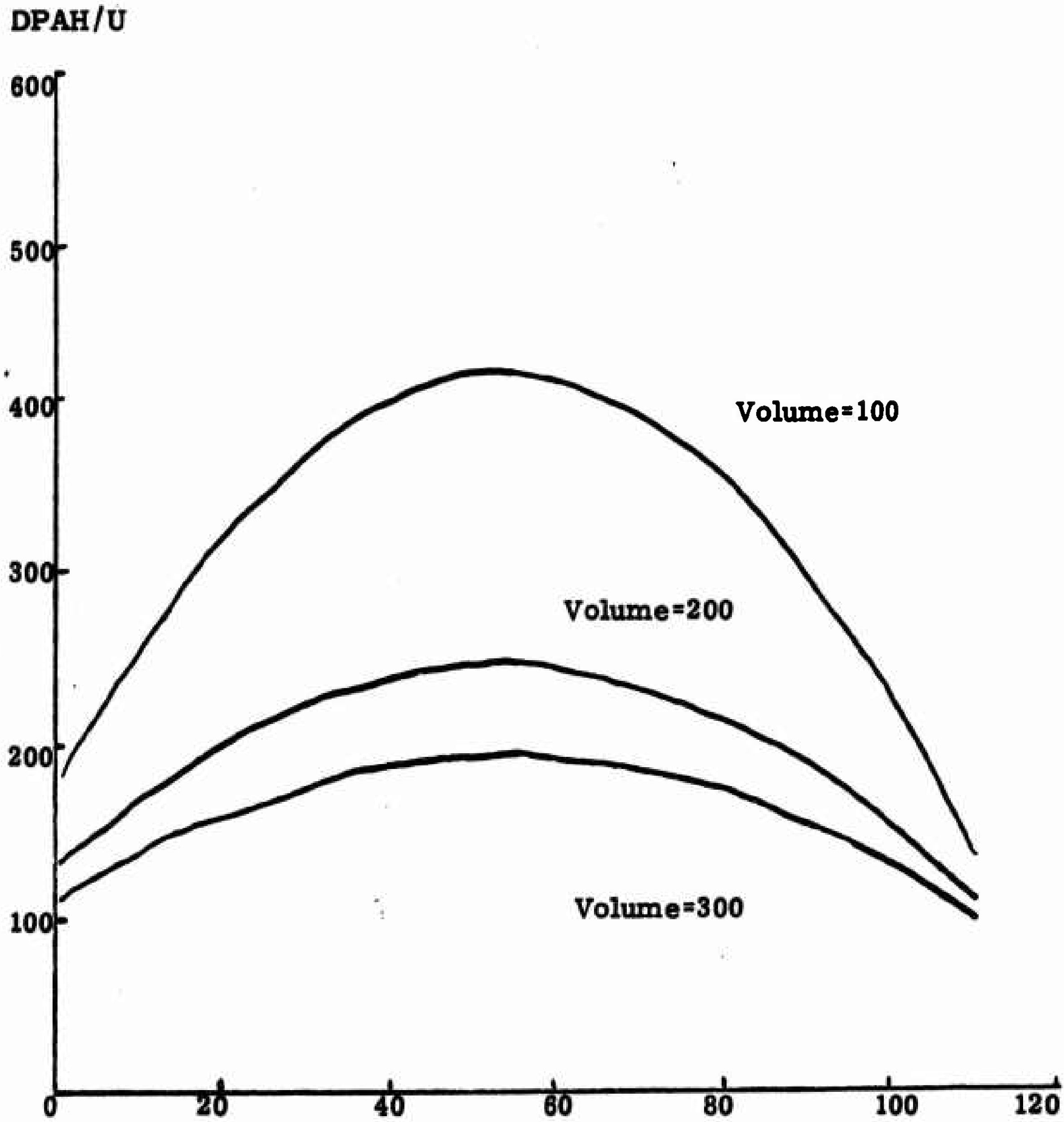


Figure 11

Direct Labor Versus Time
LN-12

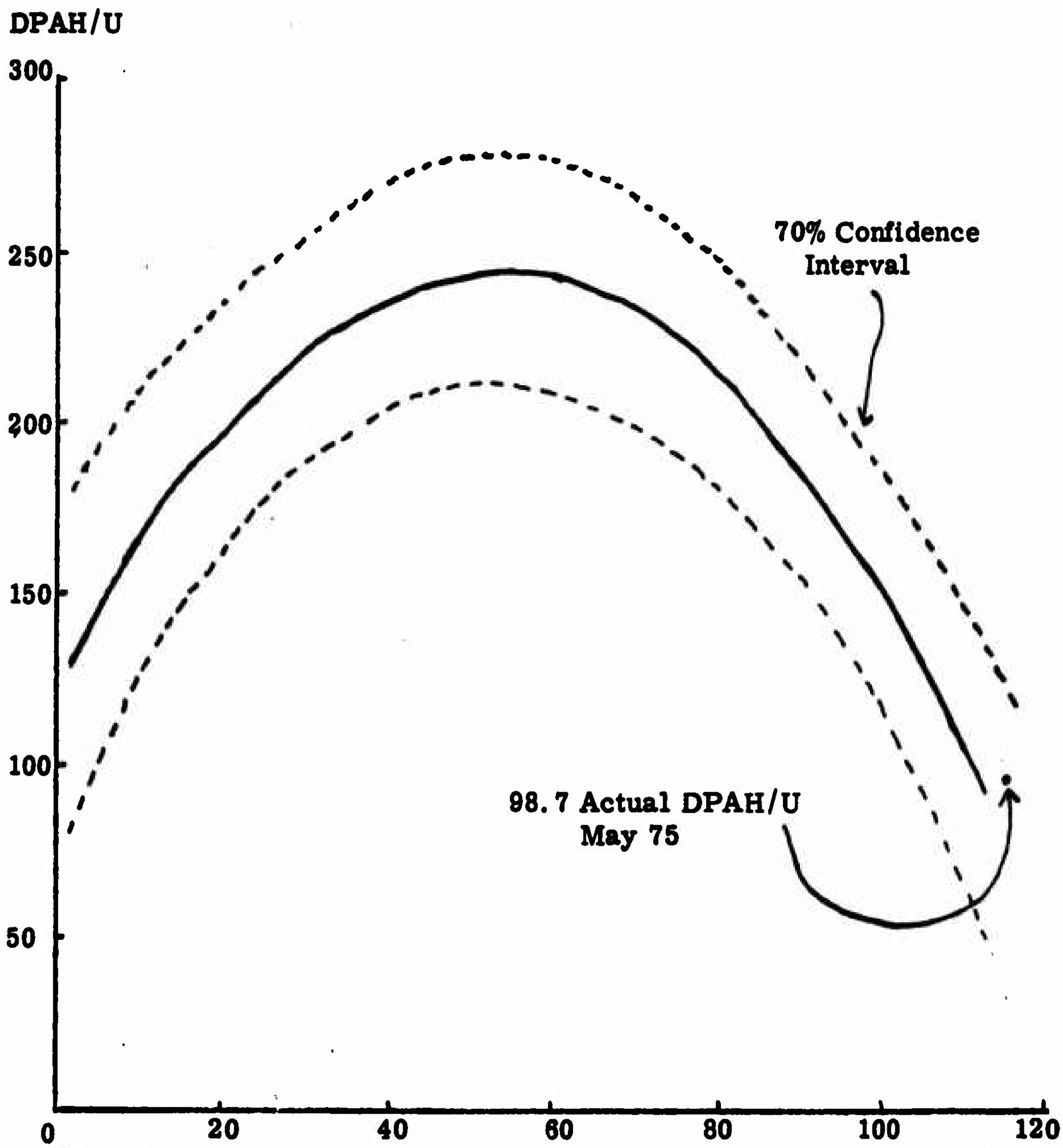


Figure 12

Direct Labor Versus Time
Fixed Volume=200 (AVE)
LN-12

applying volume and time data for a later month not used in the data set to determine how close the estimated labor hours came to actual. The month used for comparison was May 1975. Actual DPAH in that month amounted to 20550 hours for 208 units or 98.7 DPAH/U. That point is plotted in Figure 12 at time period 119 for May 75. As indicated, it does fall within the interval for one-standard deviation even though the volume level differed from the constant rate of 200 by 8 units. The predicted DPAH/U for time period 119 and a volume level of 208 units was 52.6.

It is clear from Figure 12 that the LN12 relation cannot be applied to a time period later than the last one shown on the graph (June 1975). The curve is intended to show the historical movement of DPAH/U over time. Trends can be projected into the future, but realistic values may not be derived for any of the products using the relations specified in Table II. The graph and relation do indicate that DPAH/U over time should begin to level off at a lower level than has previously been realized, assuming volume level remains relatively steady.

By comparison, Figure 13 reflects the trend in estimated DPAH/U as volume increases with time held constant. With time held at a high, current level, increasing volume results in a negatively sloped, convex curve. Here again, volume has remained within capacity as it has historically for those volume levels used in the graph. The variance becomes substantially smaller as volume increases.

A predicted value for DPAH/Unit was obtained for May 1975

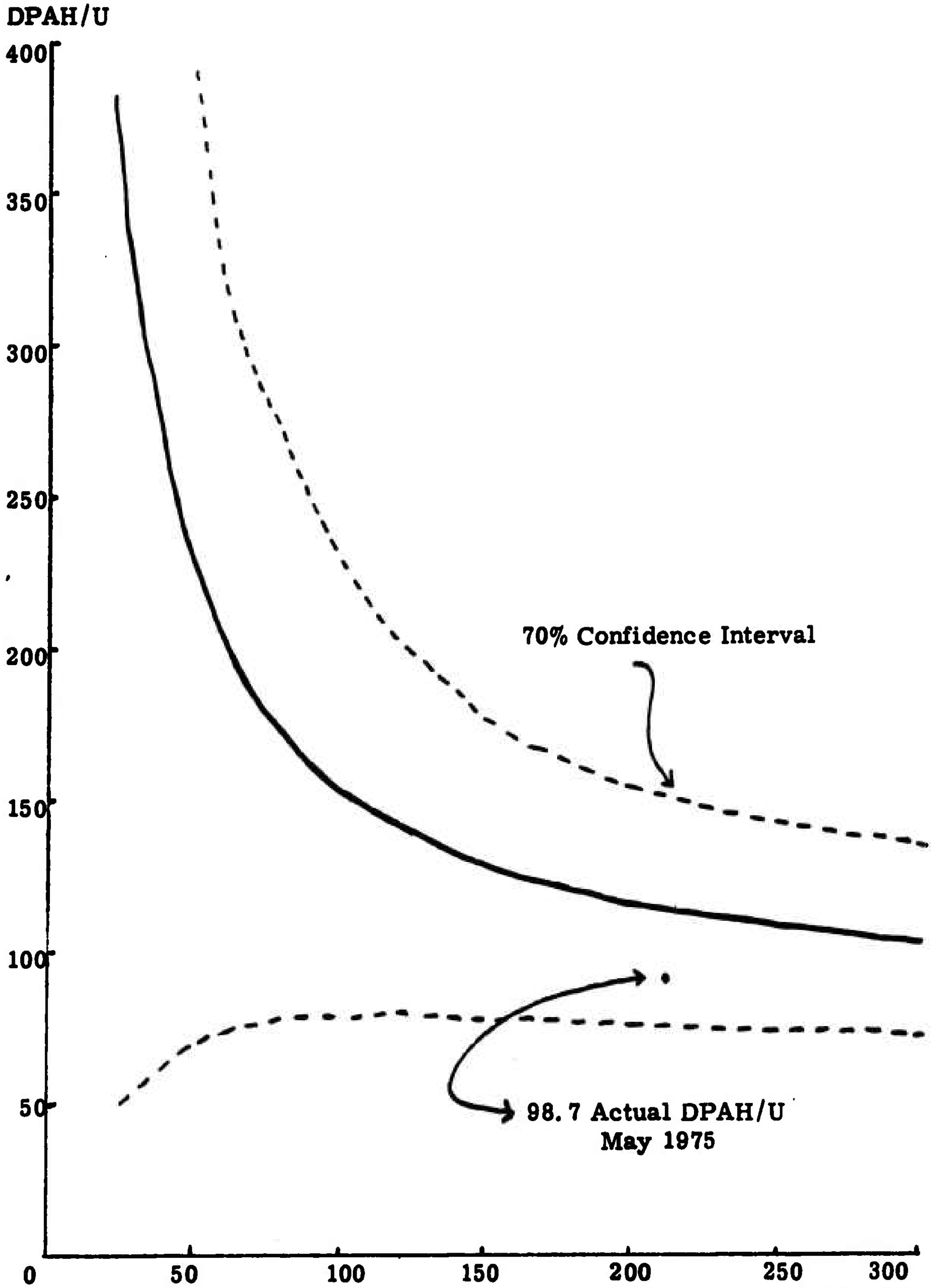


Figure 13

Direct Labor Versus Volume
Fixed Time
LN-12

(not used in the data set) at the actual volume level of 205 units. The actual DPAH/U is plotted in Figure 13 and, as indicated falls significantly close to the predicted value.

CONVERSION TO COSTS

To this point, analysis of direct labor has been in terms of hours. There are several advantages of using hours instead of costs. (Ref 7: 170) First, periodic adjustments for price changes are not required. When price indices are used in cost data, the indices themselves may contain inaccuracies. Second, with data in terms of hours, we need not worry about the effects of overtime and different wage rates until hours are converted to costs. Once the hours have been determined, wage and overtime rates can be applied using actual or projected data. Third, hourly estimates can be used directly in determining manpower requirements. Fourth, direct labor hours represent a key variable in estimating other depot costs. The use of direct labor costs rather than hours would add additional uncertainties into the variable, e.g., price changes and overtime effects. Fifth, the study of changing productivity rates over time requires the use of hours rather than costs.

A disadvantage of the use of hours is that the effect of increasing prices of labor over time is ignored. Part of the reason that direct labor requirements per unit may drop over time may be due to the increasing price of labor. It may be that, over time, it is worthwhile to substitute labor for better machinery if labor costs increase faster

than material costs. For this reason, it is beneficial to examine both labor costs and labor hours.

Direct labor cost data for the period July 1972 through December 1974 were examined and related to hours. As before, each end item was examined separately because the wage and overtime rates will vary for each product repaired. By relating historical direct labor costs to direct labor hours and time, we can identify average wage rates, overtime rates, and salary changes, and include them in estimating costs. The estimation of direct labor costs thus takes the following form:

$$DL\$_\alpha = B_0 + B_1 (DPAH)_\alpha + B_2 T_\alpha$$

where: $DL\$_\alpha$ = direct labor costs by end item per month
α = month
$DPAH_\alpha$ = direct labor hours per month
T_α = time, 1=July 1972

The DPAH coefficient represents the marginal change in labor costs due to changing hourly requirements including overtime effects. The differing requirements for highly skilled and technical manpower for each end item are also identified in the DPAH coefficient as well as in the constant. The time coefficient represents salary changes and changes in skill or overtime requirements over time.

The direct labor cost coefficients by end item are listed in Table III along with their respective standard deviations. Both DPAH and time variables are significant and positively related to labor costs as expected for all end items. While the DPAH coefficients are relatively uniform in magnitude, the range of time coefficients is substantial, indicating wide differences in labor cost factors relative to time.

TABLE III
DIRECT LABOR COST COEFFICIENTS

End Item	R^2		Constant	$DPAH_a$	$Time_a$
LN-12	.97	COEFF	-23347.26	6.8697	1701.443
		STD DEV	9466.52	.254	206.271
NS-10	.99	COEFF		6.7764	40.591
		STD DEV		.042	17.759
LGM-25	.99	COEFF	- 4272.612	7.096	400.229
		STD DEV	2030.276	.158	47.343
NS-17	.98	COEFF		6.881	1510.117
		STD DEV		.043	92.026
LN-14	.99	COEFF	- 3330.258	7.121	182.310
		STD DEV	559.770	.113	14.246
LN-7	.93	COEFF		5.885	25.870
		STD DEV		.224	4.943
NS-20	.98	COEFF		6.748	522.802
		STD DEV		.194	118.849
C5-A	.97	COEFF		6.714	174.208
		STD DEV		.181	50.553
N-16	.90	COEFF	103.354	6.913	72.052
		STD DEV	1099.13	.494	32.928
KT-71	.99	COEFF	- 678.308	6.971	60.736
		STD DEV	205.991	.129	7.608
KT-73	.95	COEFF		6.696	269.638
		STD DEV		.099	39.034
N-16GY	.99	COEFF	-1973.129	7.230	112.347
		STD DEV	333.658	.134	9.712

CONCLUSIONS

By examining the normalized labor hours per unit (Figures 4-7), the effects of time and volume on labor for all end items (Figures 12, 13 and Appendix B) and the signs and magnitudes of coefficients for each of the end items, we can make some conclusions. The direct labor requirements in the beginning months of repair are not consistent over all end items. If volume is relatively high in the initial periods, labor requirements per unit tend to be lower than if volume is extremely low. Figure 4 offers the most guidance for trends in the initial periods of a product since it includes the history of many end items. But individually, some products have high DPAH/Unit in the beginning and steadily move downward over time while others start relatively low, move upward for a time, then gradually downward.

After the initial phase of a product's repair life at the depot, generally about 2 years, all end items tend to have decreasing DPAH/Unit requirements over time. The time variable tends to dominate the effects of volume fluctuations. Several factors are probably at work here. After familiarity with the product has been achieved, workers can handle higher volumes easier. Familiarity with one new product may provide the worker with familiarity with related products to which he can switch during low volume periods of his primary product. Efficiency in the management of the workload also will improve over time. New or more adequate equipment may be a factor. In general, after the initial phase the direct labor requirements tend

to decrease as time and volume increase. The effects of time (volume constant) and volume (time constant at current period) both contribute to this tendency. Those products with consistently low volume levels do not always agree with these descriptive comments and are in some sense unpredictable.

The direct labor functions for each of the 12 enditems are included in Table II along with the approximate standard deviations and indications of what corrections/adjustments were made to each function. The NS10 provides an interesting look at the complete life of a product repaired at the depot. (See the last graph in Appendix B) Repair of this item is essentially finished and the DPAH/U requirements over time closely resemble those indicated in Figure 2a where direct labor hours per unit build up again in the last phase. A drop in volume resulting in idle time may be only one of several factors in this upward trend. Key workers may be moved to new products, leaving less experienced workers to finish repairing the phased out product. The initiative of workers may be affected as well as possible shifts in equipment or space before the old item has been completely phased out. While there is insufficient data here to make general statements about the phase down period in the repair of a product, the NS10 supports the discussion centered on Figure 2a.

CHAPTER 4
DIRECT MATERIAL

APPROACH

The approach in estimating direct material costs resembles that used for direct labor in some aspects. Product volume, direct labor hours, and time are again expected to explain at least some of the variations in direct material costs. Like labor hours, material costs per unit are expected to decline as volume increases but the reduction may be considerably less than for labor hours. Learning curve effects should have less impact in that much of the material costs reflect absolute requirements for the repair of a product, regardless of the skill level or experience of the workers. The volume level in periods subsequent to the occurrence of material costs may be significant since material costs are applied to a product primarily on the basis of direct labor hours. The product which requires direct labor in one month may not be output until the following month.

The impact of time on material costs is complicated by several factors. Direct material costs are highly dependent upon the extent of repair performed by the depot on a product. Historically, the extent of repair on nearly all end items has changed over time. In the early periods, the repair of a new end item typically involves removing and replacing a component with a new one provided by the manufacturer. Consequently, material costs per unit may be low in the initial periods while labor costs are often high because of the lack

of familiarity with the product and extensive testing that may be required. In later periods, the extent of depot repair has typically expanded to include actual repair of components which often involves more material costs. Manufacturers have also revised their products thereby increasing their complexity and altering repair requirements. The difficulty of this trend lies in the fact that material cost data do not reflect the extent or type of repair performed on a product over time. One variable which may reflect this change is direct labor hours. It is reasonable to expect that labor requirements may change if the complexity or extent of repair of a product changes significantly. However, it is not reasonable to expect that changes in direct labor requirements would necessarily produce changes in material costs. Therefore, labor hours may or may not be significant in identifying these changes in extent of repair over time.

The impact of time on direct material costs is also complicated by price changes. In this analysis, an adjustment of material cost data has been made for price changes by the use of a monthly price index (PI) which is calculated and published by the Department of Commerce. The price index, by month, is listed in Appendix A.

HYPOTHESIS

Based on this discussion, it was initially hypothesized that direct material costs, adjusted for price changes, are primarily a function of product volume, time and direct labor hours. Direct material costs

should have a positive relationship to volume, but increasing at a decreasing rate to reflect more cost effective use of materials at high volume levels. Consequently, the relationship of material cost per unit to volume would be negative. Direct material costs per unit are expected to increase with time, reflecting the age of the end item and increased magnitude of repair. Direct labor hours should have a positive relation to material costs. This would indicate that if substantial increases in labor requirements were incurred, for example, then a major change in the type or extent of repair may have been made which could increase material costs.

DEVELOPMENT OF DIRECT MATERIAL RELATIONS

Several different forms of relationships were examined to arrive at the most accurate, again primarily in terms of the coefficient of determination. Among those forms considered were the following:

$$\frac{DM_\alpha}{PI_\alpha} = B_0 + B_1(U_\alpha) + B_2(DPAH_\alpha) + B_3 T_\alpha + B_4 {T_\alpha}^2 + E_\alpha$$

$$\frac{DM_\alpha}{PI_\alpha * U_\alpha} = B_0 + B\,(U_\alpha) + B\,(DPAH_\alpha) + B\;T_\alpha + B\;{T_\alpha}^2 + E_\alpha$$

$$\frac{DM_\alpha}{PI_\alpha} = B_0\, U_\alpha^{B_1}\, T_\alpha^{B_2} + E_\alpha$$

where: α = month
PI = Price index for month α
U = Number of units produced in month α
T = Time, expressed in consecutive integers, 1 = July 1972
DPAH = Direct labor hours in month α
E = Error

The first form listed consistently provided better relations in terms of R^2. A volume variable for period $\alpha+1$ was also considered

but was found irrelevant. Each form was also tested using quarterly totals rather than monthly (a) data in an attempt to smooth out wide monthly fluctuations. Many of the relations were improved using quarterly totals. As a result, equations were also derived using quarterly data and, if the R^2 was substantially improved those equations are reported.

The criteria used for determining a good relationship were the same as those discussed earlier for direct labor. The t and F statistics for each coefficient were examined for significance. Historical data from July 1972 through June 1974 were used for products whose depot history extended back to July 1972. Otherwise, the entire history of the product through June 1974 was used. Direct material data are included in Appendix A. Graphs showing direct material costs per direct labor hour versus direct labor hours are in Appendix C.

The coefficients and corresponding standard deviations are listed in Table IV for the direct material function of the following form:

$$\frac{DM\$_a}{PI_a} = B_0 + B_1 DPAH_a + B_2 U_a + B_3 T_a + B_4 T_a^2$$

Each factor is on either a monthly or quarterly basis as labeled in Table IV. Those functions with relatively low R^2 represent products which had substantial changes in definition or in the type or extent of repair. Predictions for material costs in these areas must take into account the specific type of repair required in addition to the relation specified here. That information should be related to the historical material costs of periods requiring similar repair.

TABLE IV
DIRECT MATERIAL COEFFICIENTS

End Item		R^2	Constant Term	Variables: $DPAH_a$	Variables: $Unit_a$	Variables: $Time_a$	Variables: $Time_a^2$	Mo. or Qtrly.
LN12	COEFF	.89	-449.25	.04				MO
	STD DEV		104.26	.003				
NS10	COEFF	.97		.005	2.42			QTR
	STD DEV			.003	1.57			
LGM25	COEFF	.76		.016				QTR
	STD DEV			.0005				
NS17	COEFF	.70		.02		711.29	-83.40	QTR
	STD DEV			.006		359.49	40.15	
LN14	COEFF	.61		.02		26.69	-1.27	MO
	STD DEV			.01		10.24	.42	
LN7	COEFF	.92	10.62	-.004	1.64	-1.81		QTR
	STD DEV		5.37	.002	.82	.34		
NS20	COEFF	.76		.05		-182.85		QTR
	STD DEV			.005		29.25		
C5A	COEFF	.50		.02		10.99	-.54	MO
	STD DEV			.004		3.87	.15	
N16	COEFF	.50		.04		-4.38	.17	MO
	STD DEV			.006		2.73	.11	
KT71	COEFF	.77		.04		-7.07		QTR
	STD DEV			.006		3.24		
KT73	COEFF	.84		.01		-134.72	17.67	QTR
	STD DEV			.003		39.64	4.32	
N16GY	COEFF	.46		.03		-4.47	.23	MO
	STD DEV			.005		2.26	.11	

The most significant variable was direct labor hours which had a significant positive relationship to direct material costs for every end item. Time was second in importance but was not significant for all end items. As indicated in Table IV, the fit was greatly improved for some of the products by using quarterly data as opposed to monthly.

Each relation was tested for the existence of Multicollinearity, Heteroscedasticity, and Autocorrelation as discussed in the previous chapter. In the case of the direct material relations, one had an autocorrelation problem and was corrected (LGM25). No problems of Multicollinearity or Heteroscedasticity were found.

It is important to note that the relations differ a great deal among end items. DPAH was the only consistent indicator which highlights the fact that direct labor hours are the key factor in assigning material costs to end items.

VALIDATION

The individual effects of direct labor, volume level, and time on material costs are worth examination. In the case of the LN12 for example, the direct labor hours variable was dominant while time and volume level were insignificant in explaining variations in material costs. In Figure 14, the positive relationship of material costs to direct labor hours is shown with other factors held constant. The one-standard deviation interval is also indicated. The relation is not valid for volume levels at or below 10,000 direct labor hours. The range

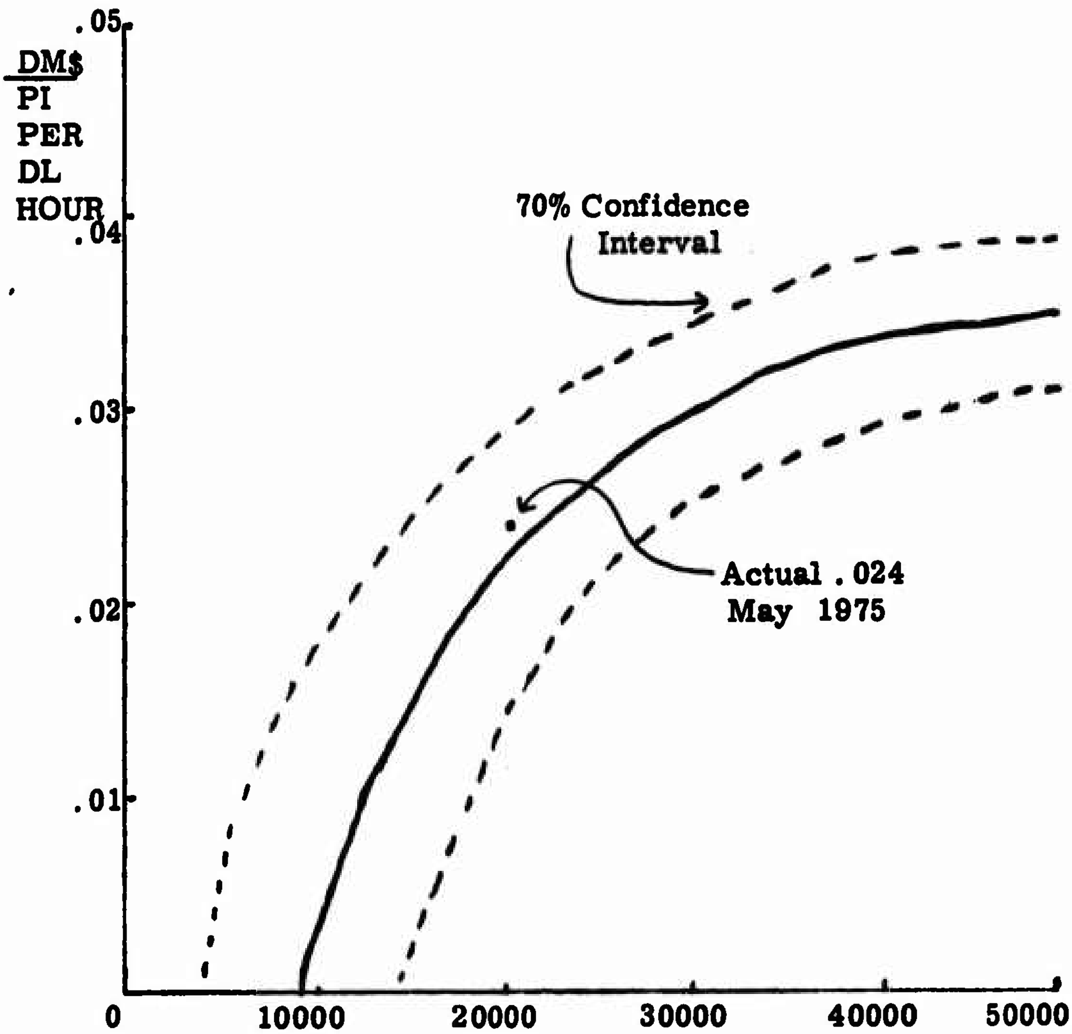


Figure 14

Direct Material Costs Versus DL Hours
(Volume and Time Constant)
LN-12

of validity for all relations is dependent upon the range of the historical data base.

The NS17 case has a relatively low R^2 but is significantly effected by time and volume and has a relationship which is representative of most products. The effect of time on material costs, other variables held constant, is plotted in Figure 15. The relationship of volume to material costs for all end items is plotted in Appendix C but other variables are not held constant in those graphs. In Figure 15, direct labor hours are held at an average level to indicate the direct labor impact over time. While the slope of this curve indicates very low or zero material costs in later periods, this will obviously not be the case. The graph is intended to show the historical trends of material costs per direct labor hour over time. The indications are that the material requirements for NS17 will level out at a lower level than occurred in earlier time periods.

The relationship of direct labor hours to NS17 direct material costs per direct labor hour is portrayed in Figure 16 with the 70% confidence interval. Like the LN12, the slope is increasing slightly at high hourly values but is less effected at low values. This difference implies that the material requirements are relatively fixed for the NS17 compared with the repair time required.

The actual LN12 direct material cost per direct labor hour, adjusted for price changes, is plotted in Figure 14 for May 1975, a

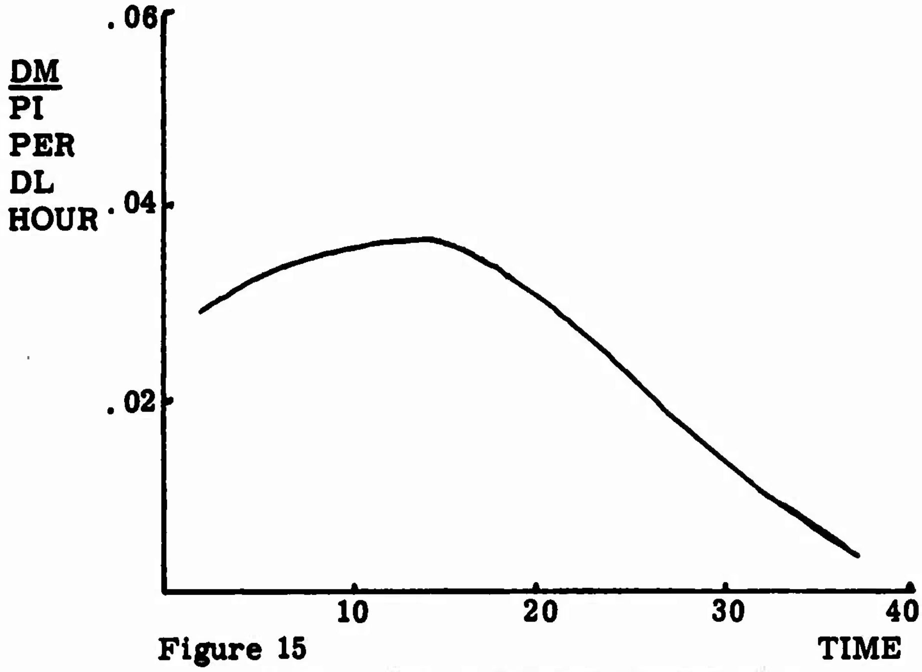


Figure 15
Direct Material Costs Versus Time
(DPAH and Volume Constant)
NS-17

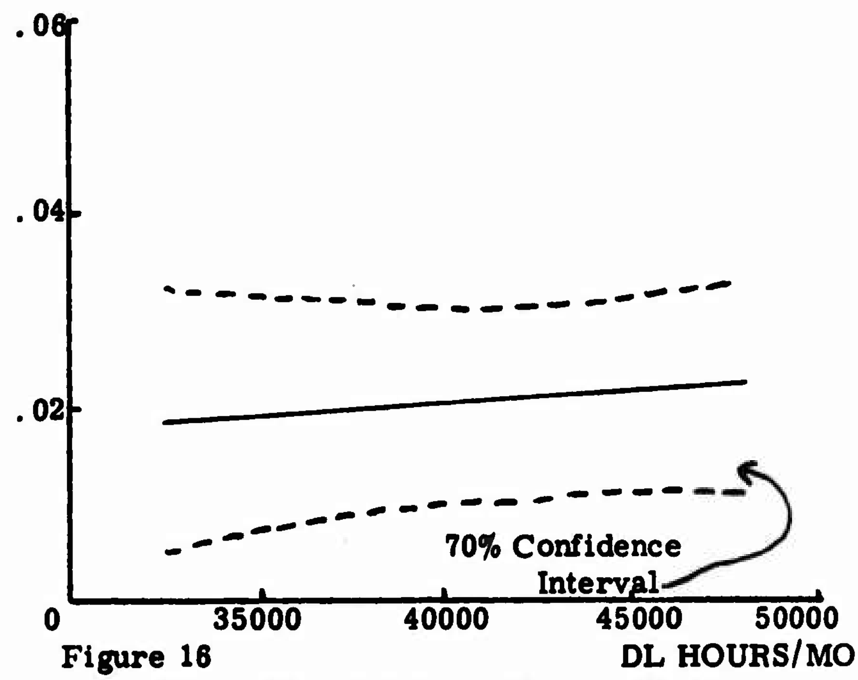


Figure 16
Direct Material Costs Versus DL Hours
(Time and Volume Constant)
NS-17

period subsequent to those used in the data base. The actual figure of 0.024 falls well within one standard deviation of the predicted 0.022 given the historical factors of 20,578 DPAH, 208 units, a price index of 172.3 and $87,435 in direct material costs.

SUMMARY

Direct labor hours, time and volume level generally did an adequate job of explaining direct material costs. Monthly material cost figures seem to fluctuate widely, however, and quarterly totals provide a more predictable data base for most end items. Estimates of material costs will require an examination of the type and extent of repair performed in addition to the use of any relation discussed here. Much of the fluctuation caused by the extent of repair is identified by direct labor hours. However, a great deal is left unexplained in some products such as the C5A and the N16. When the time variable is significant, it may create unrealistic results for estimating costs in later periods. In such cases, the relation should be used to determine the trend of costs in future periods, not the estimated cost itself.

CHAPTER 5
OVERHEAD

APPROACH

The estimation of overhead costs for a given workload and the application of those costs to individual end items is vitally important in the cost analysis of various workloads. This will become more evident in Chapter 7 where it is shown that the variable and fixed overhead costs attributed to a product are driving factors in determining a product's contribution to the relative efficiency of a depot's potential workload.

Variable overhead will be discussed first and primarily involves costs of the maintenance sector. Variable overhead costs are assigned to end items generally on the basis of direct labor hours. It is expected that direct labor hours will have a positive relation to variable overhead costs. However, variable overhead costs per direct labor hour should be negatively related to total direct labor hours. Such a condition implies that variable overhead will not increase proportionately with direct labor but will increase at a slower rate. Although direct labor is expected to be the primary contributor to variable overhead, improved management of resources over time should also help reduce fluctuations in variable overhead. Furthermore, because of some unexplained variations in direct labor requirements, volume level in terms of units of output may offer some explanation that direct labor hours would fail to highlight. For these reasons, the hypothesized

estimator for variable overhead took the following form:

$$\frac{VarOH\$_{\alpha}}{PI_{\alpha}} = B_0 + B_1\, DPAH_{\alpha} + B_2 U_{\alpha} + B_3 T_{\alpha} + B_4 T_{\alpha}^{2} + E_{\alpha}$$

where: α = Month
PI_{α} = Price Index for month α
$DPAH_{\alpha}$ = Direct labor hours in month α
U_{α} = Units of an end item in month α
T_{α} = Time, expressed in consecutive integers by month, 1=July 72
T_{α}^{2} = Time variable squared
E_{α} = Error

As with other cost data, variable overhead costs were adjusted for price changes by applying a price index (Appendix A).

Fixed overhead involves a different approach. Costs in this category are allocated to products on the basis of actual, required support such as the number of inspectors required and number of square feet of facility space required per end item. Those requirements are expected to change, however, as more experience is gained on a product and as volume levels change. One approach would be to derive all requirements in each fixed overhead category and develop a factor for each one by end item. Costs could then be calculated for each category and aggregated to derive total fixed overhead costs for each product. This may be the most accurate approach, but is very time consuming and labor intensive. Furthermore, requirements change over time and the factors soon become outdated.

Another method is to first examine how total fixed overhead has varied over time and as volume levels change. It is reasonable to expect that much of the changes in facility, equipment, fixed support

personnel and other fixed overhead categories are highly correlated with time and volume level. If a close estimate of total monthly fixed overhead costs can be derived, that total can be allocated to specific products on the basis of the proportion of the depot workload that each product entails. Depot workload is again stated best in terms of direct labor hours. In mathematical notation, this approach is outlined below:

$$\frac{TFOH_{\alpha}}{GSAL_{\alpha}} = B_0 + B_1 T_{\alpha} + B_2 TDPAH_{\alpha} + E_{\alpha}$$

$$\frac{FOH_{\alpha i}}{GSAL_{\alpha}} = B_0 + B_1 \left[\widehat{\frac{TFOH_{\alpha}}{GSAL_{\alpha}}}\right] \left[\frac{DPAH_{\alpha i}}{TDPAH_{\alpha}}\right] + E_{\alpha}$$

where: α = Month
i = End item
$TFOH_{\alpha}$ = Total fixed overhead, all end items, in month α
$GSAL_{\alpha}$ = Salary adjustment factor
T_{α} = Time, expressed in consecutive integers by month, 1=July 72
$TDPAH_{\alpha}$ = Total direct labor hours, all end items, in month α
$FOH_{\alpha i}$ = Fixed overhead cost per end item per month
$DPAH_{\alpha i}$ = Direct labor hours per end item per month
E_{α} = Error

DERIVATION OF VARIABLE OVERHEAD RELATIONS

The historical relationship of variable overhead costs to direct labor hours is illustrated by the graphs in Appendix D. In general, variable overhead cost per direct labor hour has been negatively related to direct labor hours. The historical relationship of time to variable overhead was examined but indicated no clear trends. Trends are probably clouded by changes in the definition of variable overhead over time.

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Cost estimating relations were developed using the basic form described earlier for variable overhead. Coefficients and their respective standard deviations are included in Table V. In an attempt to keep the relation simple, no major changes from this design were considered. Also, relatively high coefficients of determination (R^2) were achieved using the basic form. The direct labor hours variable was dominant as expected and all coefficients were positive. Time was the second most influential variable and had a negative relationship to overhead costs in most cases. Where the coefficient was positive, a negative T^2 variable was also significant which counteracted the positive T effects. Significance of variables was primarily determined by examining the ratio of the coefficient to its standard deviation (t statistic).

Tests were made for the existence of multicollinearity by fitting each independent variable against the others in a least squares regression model. The highest R^2 in this test was .64 and occurred with the direct labor hours variable. This was not considered high enough to drop the variable. In tests for autocorrelation, the Durbin-Watson statistic indicated "no conclusion" for nearly half of the end items. There were no definite indications of positive or negative autocorrelation. Two end items had heteroscedastic indications, one with regard to time and the other with regard to direct labor hours. Those end items were the N16GY and KT73 respectively, and the proper adjustments were made in both cases. Chapter 3 discusses these problem areas and adjustments in detail.

TABLE V
VARIABLE OVERHEAD COEFFICIENTS

End Item	R^2		Constant Term	Variables: $DPAH_\alpha$	$Units_\alpha$	$Time_\alpha$	$Time_\alpha^2$
LN12	.94	COEFF	1103.368	.026	-4.168	-40.374	1.148
		STD DEV	287.966	.003	1.604	12.444	.478
NS10	.98	COEFF	60.475	.0346		-8.951	.3715
		STD DEV	30.506	.0038		3.197	.1383
LGM25	.85	COEFF	97.918	.028		-9.471	.330
		STD DEV	35.386	.003		3.565	.138
NS17	.88	COEFF		.04		-16.234	
		STD DEV		.0009		2.548	
LN14	.41	COEFF	70.938		2.127		
		STD DEV	22.448		.762		
LN7	.90	COEFF		.0414		-.2327	
		STD DEV		.002		.066	
NS20	.92	COEFF	83.264	.0296		-4.363	
		STD DEV	15.325	.002		.874	
C5A	.86	COEFF		.068		-4.653	
		STD DEV		.003		.990	
N16	.76	COEFF		.051	5.891	3.825	-.317
		STD DEV		.009	2.942	2.185	.091
KT71	.90	COEFF		.0395			
		STD DEV		.0014			
KT73	.68	COEFF	-145.80	.057			
		STD DEV	62.168	.008			
N16GY	.68	COEFF		.041			
		STD DEV		.002			

The marginal effect of volume level on variable overhead costs per direct labor hour is highlighted in Figure 17 using the LN12 as an example. Volume level, in terms of units of output, has a substantial effect on variable overhead in lower levels of direct labor hours but has less impact at high levels. In Figure 18, units of output are held constant at an average level of 200 for the LN12 and the 70% confidence interval is indicated. In both figures, time is held constant at a current (July 75) point. The estimate of variable overhead per direct labor hour is lower and more accurate at high levels of direct labor hours.

In Figure 19 units of output are held constant at an average of 200 and DPAH at 22,000 to show the historical and predicted impact of time on variable overhead per direct labor hour. While this trend is only applicable for a constant volume level over time, it does indicate an increase in variable overhead per direct labor hour in the later periods of the data base and projects an increase in future periods. The definition of variable overhead may have changed over time. If that is the case, the change in slope of this curve would be explained, in part at least, by additions or deletions to the defined categories of variable overhead. The actual data point for May 1975, a period subsequent to the data base, is plotted in Figures 18 and 19. In both instances, the point falls within 2 standard deviations of the predicted value, but not within one as indicated.

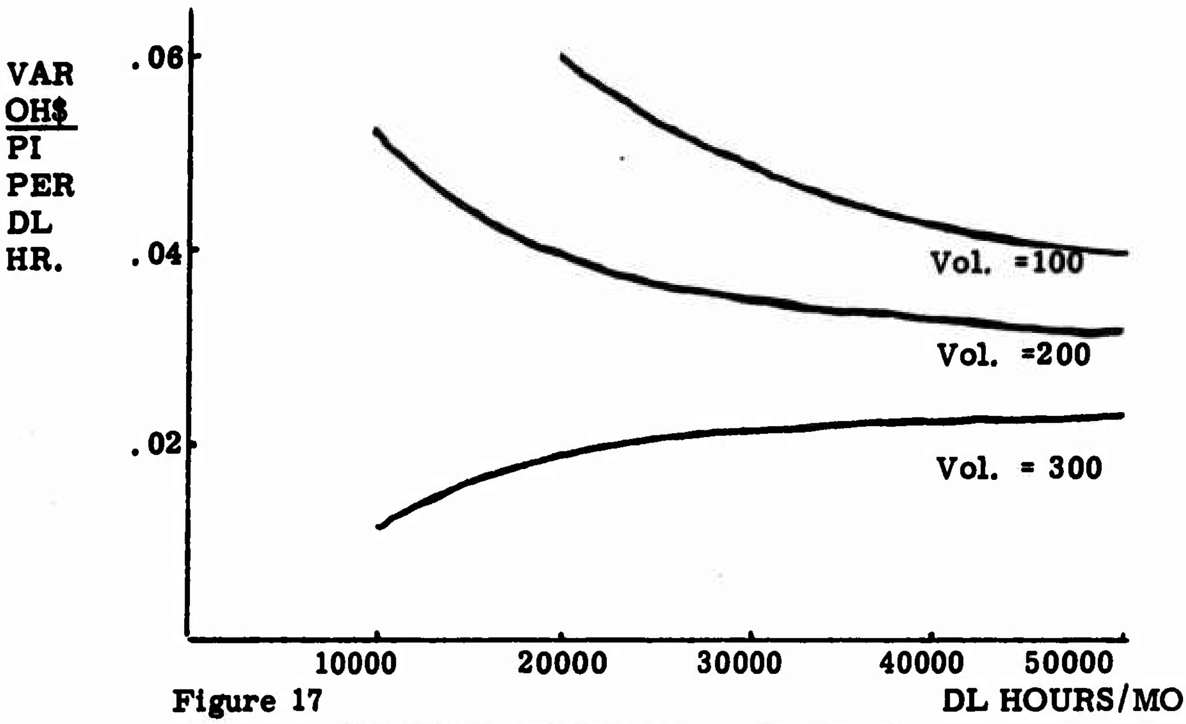

Figure 17
Variable Overhead Versus DL Hours
(Time Constant)
LN-12

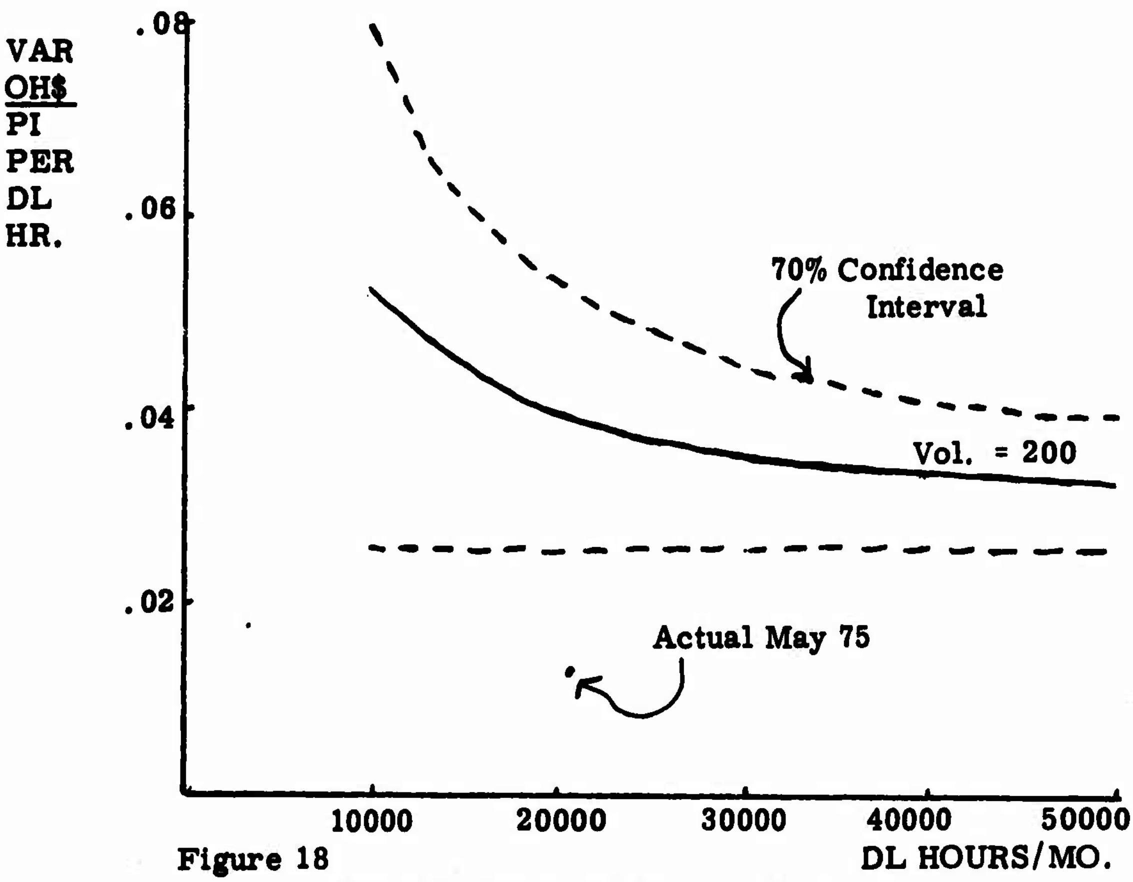

Figure 18
Variable Overhead Versus DL Hours
(Time and Volume Constant)
LN-12

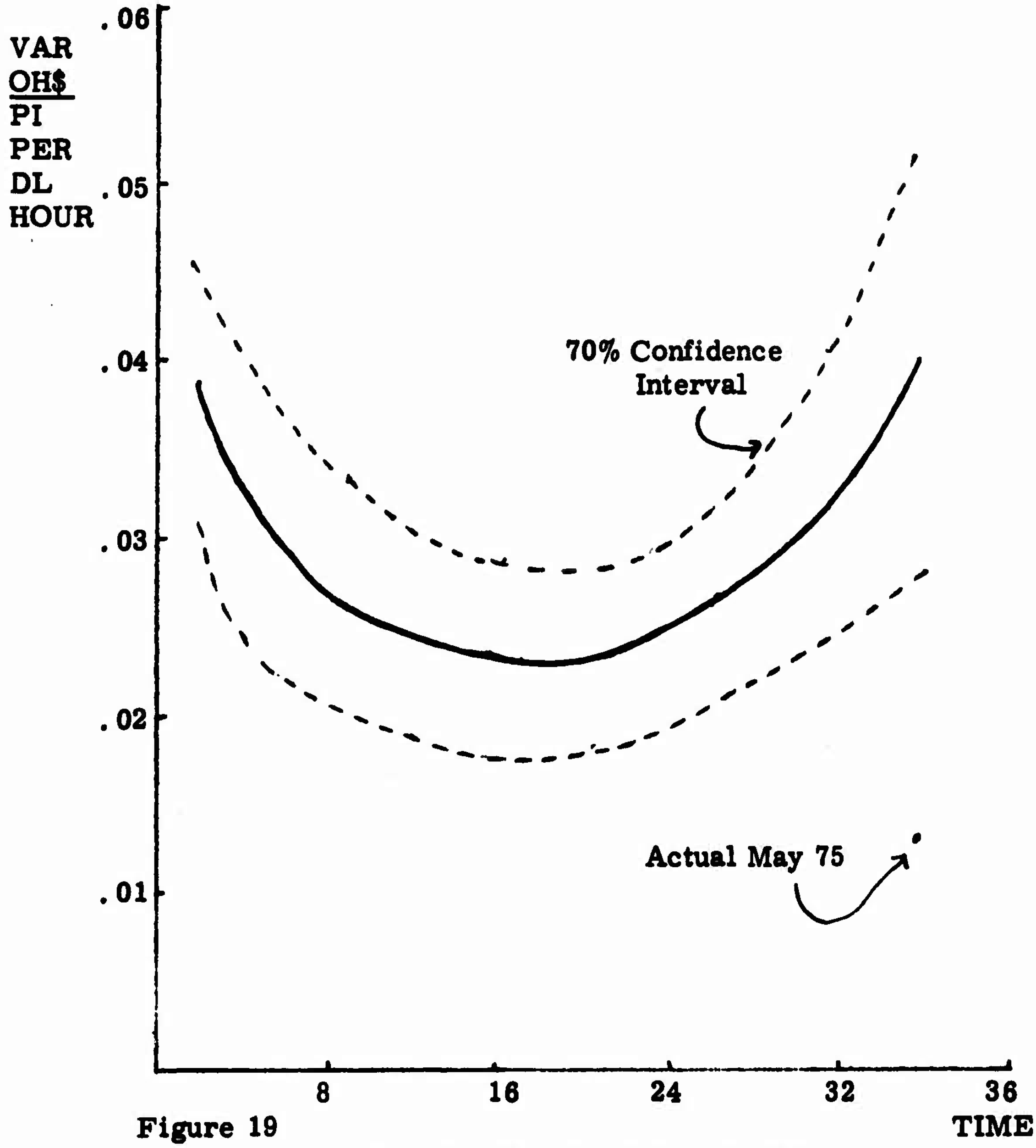

Figure 19

Variable Overhead Versus Time
(DPAH, Volume Constant)
LN-12

DERIVATION OF FIXED OVERHEAD RELATIONS

The cost elements that make up "Fixed Overhead" in this discussion are presented in the definitions section of Chapter 1. In this analysis, General and Administrative expenses (G&A) are added to Fixed Overhead and the sum referred to as Fixed Overhead (FOH). Total fixed overhead costs are not expected to vary over time to the extent that the other cost categories have, especially after the fixed costs are adjusted for salary increases. In reality, however, "fixed" costs do vary somewhat over time due to changes in definition, changing management and management policies, high fluctuations in production level and possibly other factors. Direct labor hours are expected to account for most of the fluctuation due to increases or decreases in workload. Consequently, total fixed overhead costs, adjusted for salary fluctuations, are expected to be a function of time and direct labor hours plus other non-quantifiable factors. The relation for total fixed overhead, (TFOH), involving all 18 end items, took the following final form:

$$\frac{TFOH_\alpha}{GSAL_\alpha} = 17.923 + .234\ T_\alpha + .00018\ TDPAH_\alpha$$

where: α = Month, 1=July 1972

$TFOH_\alpha$ = Total Fixed Overhead and G&A for 18 end items in month α (Appendix A)

$GSAL_\alpha$ = Salary adjustment factor (Appendix A)

T_α = Time, expressed in consecutive integers by month, 1=July 1972

$TDPAH_\alpha$ = Total direct labor hours for the 18 end items in month α (Appendix A)

the t statistic for significance of coefficients was greater than or equal to 3.0 for all variables. It is reasonable to expect a large constant term for fixed overhead. The slope of this relation over time, DPAH held constant, is relatively flat as shown in Figure 20. Historically, fixed overhead and G&A expenses per direct labor hour, adjusted for salary changes, have increased with time. (Figure 21) There has also been, in general, a positive relation between direct labor hours and fixed overhead per direct labor hour, although not as clear a relationship as with time (Appendix E). With those indications, the positive signs for both the time and DPAH coefficients are reasonable.

The coefficients for combined fixed overhead and G&A expenses by individual end item are listed in Table VI along with their respective standard deviations. The general form of the relation is as follows:

$$\frac{(FOH + G\&A)_{\alpha i}}{GSAL_\alpha} = B_0 + B_1 \left[\frac{\widehat{TFOH_\alpha}}{GSAL_\alpha}\right] \left[\frac{DPAH_{\alpha i}}{TDPAH_\alpha}\right]$$

where: α = Month, 1=July 72

i = End item

$GSAL_\alpha$ = Salary adjustment factor

$\dfrac{\widehat{TFOH_\alpha}}{GSAL_\alpha}$ = Estimated total fixed overhead plus G&A expenses for all end items (18) in month α, adjusted for salary changes

$DPAH_{\alpha i}$ = Direct labor hours in month α for end item i

$TDPAH_\alpha$ = Total direct labor hours in month α for all end items (18)

Each relation was examined for the existence of autocorrelation, heteroscedasticity and multicollinearity. Five of the relations had indications of autocorrelation with respect to the independent variable. No other problems were detected. Corrections for autocorrelation

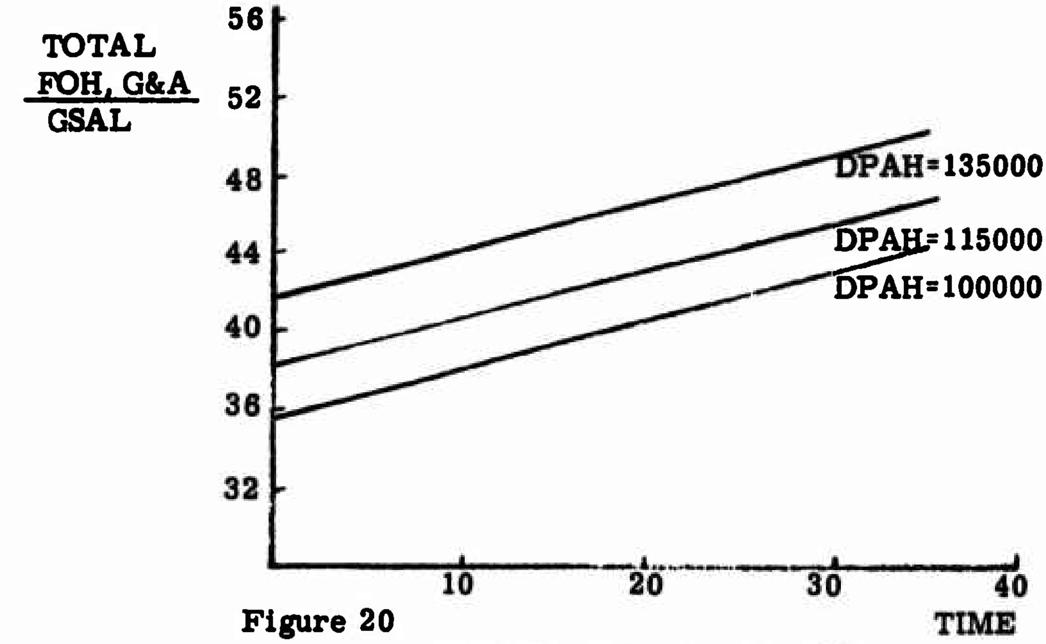

Figure 20

Total Fixed Overhead, G&A
Versus Time

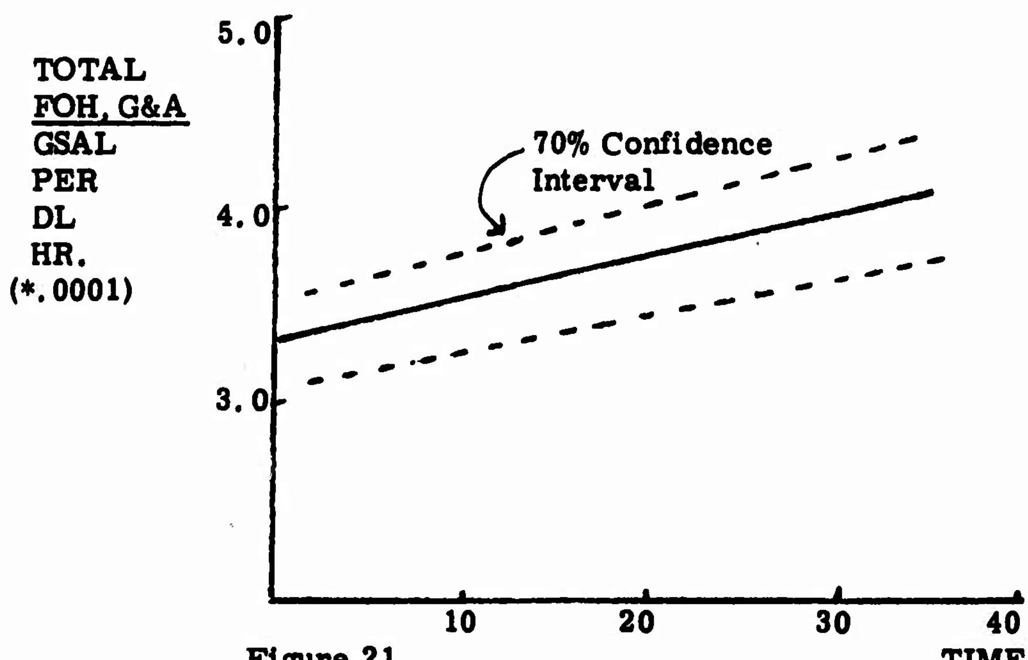

Figure 21

Total Fixed Overhead, G&A
Per DL HR Versus Time
(DPAH = 115000)

TABLE VI
FIXED OVERHEAD, G&A
COEFFICIENTS

End Item	R^2		Constant	$\widehat{\left[\frac{TFOH_a}{GSAL_a}\right]}$	$\left[\frac{DPAH_{ai}}{TDPAH_a}\right]$	ADJ*
LN12	.84	COEFF	2.0841	.9618		
		STD DEV	.860	.0887		
NS10	.92	COEFF		.8307		
		STD DEV		.0292		
LGM25	.80	COEFF	-.235	.8411		1
		STD DEV	.362	.0906		
NS17	.83	COEFF		1.0506		
		STD DEV		.1013		
LN14	.87	COEFF		1.1888		
		STD DEV		.0239		
LN7	.97	COEFF	.0121	.9846		1
		STD DEV	.0074	.0377		
NS20	.96	COEFF		.9696		
		STD DEV		.0392		
C5A	.91	COEFF		.6825		1
		STD DEV		.0356		
N16	.52	COEFF		.6300		1
		STD DEV		.0645		
KT71	.96	COEFF		.7359		1
		STD DEV		.0258		
KT73	.74	COEFF		.7542		1
		STD DEV		.0393		
N16GY	.49	COEFF	.2006	.4300		
		STD DEV	.0546	.0929		

*ADJ: 1=Corrected for Autocorrelation

were made on those coefficients indicated in Table VI (see Chapter 3 for more detailed explanation of these problem areas.)

In those relations without a constant term, the coefficient for the independent variable is an indication of the share of overhead costs assigned to each end item. A coefficient of 1.0 would verify that the overhead burden assigned to a product is directly proportionate with the percentage of direct labor hours devoted to that product. On this basis, the last five end items listed in Table VI have carried a low share of the fixed overhead load.

SUMMARY

Direct labor hours are used as the primary estimator for both variable and fixed overhead but in different ways. With variable costs, direct labor serves as an explainer of month to month fluctuations due to production volume. With fixed costs, direct labor is used to assign a proportionate share of costs to each end item. In both categories, relatively poor relations, in terms of R^2, occurred for three products, namely LN14, KT73 and N16. Discrepancies may exist in the data for these items and further examination of the data should be made.

CHAPTER 6
EQUIPMENT AND FACILITIES

Facility and equipment costs will not be emphasized in this thesis. In the analysis chapter to follow, facility and equipment capabilities will remain at existing levels. In many analyses, it is realistic to consider facility and equipment costs as sunk costs. Such unrecoverable expenses should not influence the results of a workload analysis unless additional facilities/equipment are required. However, economic models which examine major changes in workload must include an analysis of the corresponding changes in facility and equipment requirements. A proposed approach to that type of analysis will be briefly discussed here.

REPAIR LINE CONCEPT

Each product repaired at a depot requires a specific set of equipment, or repair line, which in turn requires a specific block of space within the facility. An initial outlay of capital expense is required to add a new and different end item to the depot workload in terms of a new repair line. Initial equipment/facility expenditures are based on an estimate of maximum workload requirements for the new end item. If maximum volume level requirements (units produced) exceed original estimates at some later time, additional equipment and possibly facilities would have to be acquired. The cost curve would take on a shape similar to that in Figure 22.

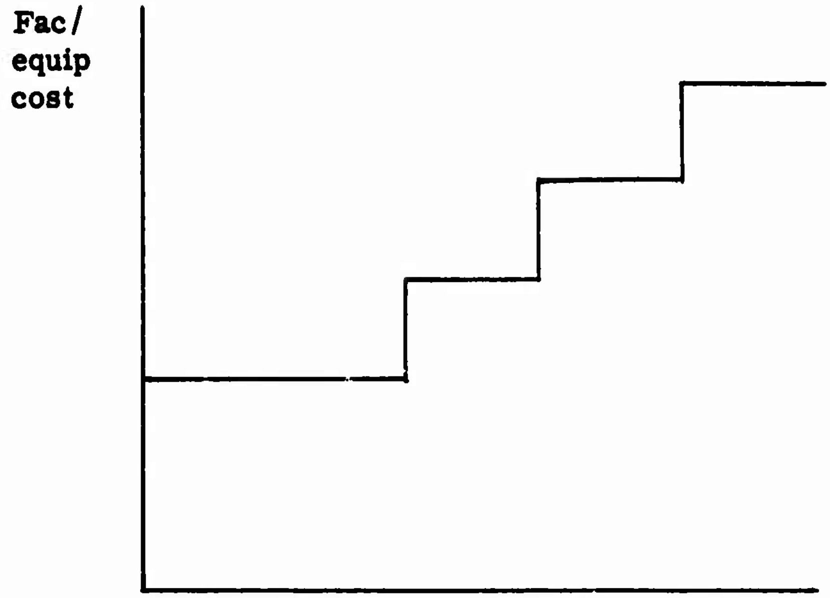

Figure 22
Capital Investment
VS Capacity

Each additional increment of facilities/equipment could handle a specific range of production volume.

In the case of facilities, the original AGMC economic model required an input table which identified specific blocks of space available for each repair line or other type of work. This was a cumbersome table, however, even for a small depot such as AGMC. In addition, it required the input of more detail than is required for a workload cost analysis. Facility requirements should be in terms of square or cubic feet per end item or range of production volume. On this basis, existing blocks of space could be converted to other uses without effecting the validity of the analysis. When specialized space requirements are involved, such as clean room space, facility

requirements should be examined by category, e. g. common facility and clean room facility requirements per end item. Space requirements in terms of square or cubic feet are then converted to dollar values on the basis of current contractor rates for each type of space required. Careful attention should always be given to the possibility of converting existing space into the type of space required for the added workload, e. g. administration space to production space.

For equipment, costs should be in terms of repair line requirements for a given capacity. Several alternatives for charging off equipment costs over time are available. A paper by Rogge of AGMC discusses two approaches and presents a computer program for amortizing costs over time (Ref 8). Regardless of the system used, equipment costs for each time period should be applied to the end item for which the equipment was purchased. Care should also be taken to apply current equipment values to workload analyses, not the original cost of equipment.

A cost curve resembling Figure 22 is required for each repair line, which may repair one or more end items. For easier application to an economic model, the steps can be averaged out to form a linear or non-linear function, the slope of which would indicate the average increase in capacity per dollar of capital investment at any given level of capacity.

SHARED REPAIR LINES

Facility and equipment cost analysis is complicated by the fact

that a single repair line is often used for more than one product. Thus, we face the problem of allocating shared equipment and facility costs to specific end items. Assume, for example, that the NS17 and NS20 share the same basic repair line and that repair of the NS17 began three years before the NS20. When production began, equipment was acquired and facilities made available for the NS17 only. When the NS20 entered the system three years later, the NS17 was not using the repair line to full capacity. The NS20 could therefore be added to the system without any outlay of capital investment. For purposes of workload cost analysis, the costs of equipment/facilities required for the repair line could either be applied to both products or the NS17 only. When the objective is to determine whether or not to add the NS20 to the AGMC workload, we must realize in monetary terms the benefit of the repair line already in existence at AGMC. It is therefore more accurate, from an economies of scale standpoint, to apply the costs of the equipment/facilities to the product for which they were originally acquired. This policy would highlight the advantage of repairing a product at a depot where the required capacity and resources are already available. In our example, if production level of the NS20 later increased to a point where additional capital outlay is required for the repair line, then the additional outlay would appropriately be charged to the NS20.

The cost outlay for capital necessary to repair a product is usually very substantial. The analyst must take care in applying such

costs to the appropriate portion of the potential workload. At the same time, it is important to ensure that the application of sunk costs does not drive the results of a workload decision.

CHAPTER 7
WORKLOAD ANALYSIS

INTRODUCTION

We are now at the point of aggregating costs and conducting an economic analysis of a workload in terms of differing mixes of products repaired and various volume levels. The cost analysis of potential workloads is a complex problem and requires some assumptions which are controversial. Probably chief among these is the assumption of a common measure of merit.

Any given workload at a repair depot is composed of end items which differ in terms of initial cost, size, complexity and many other aspects. We would like to examine a given workload mix and determine whether it is more cost effective to increase, decrease or remain at the given volume level. We would also like to take a given volume capacity in terms of manpower, facilities and equipment, and find a mix of products to repair which would maximize the cost effectiveness of the depot. In order to conduct such analyses, it is first necessary to define "Cost Effectiveness." An appropriate measure of merit must be established. Appropriate costs must be applied to the measure chosen in such a way that will prevent overemphasis or underemphasis of each cost factor. These tasks will be discussed in this section.

THE MEASURE OF MERIT PROBLEM

Total cost per unit is one possible and convenient measure to

use in comparing products and volume levels. However, cost per unit, in itself, is an unsatisfactory measure because it penalizes the larger or more complex end items. Because a product requires a large dollar amount of direct material, for example, does not mean that the product should be dropped from the depot workload. Total cost at any given volume level does not give a true indication of cost effectiveness but does give some indication of economies of scale effects. It may also provide a means of arriving at an accurate indicator even though it is not one in itself.

An adjusted cost per unit is another possible output measure. Total cost could be adjusted by deleting all cost elements which should not be considered in studying the economical benefits of various depot workloads. New test equipment, for example, could be considered not applicable in an economies of scale study in that someone would be required to purchase such equipment regardless of where the item was repaired. Consequently, it could be reasoned that such a cost need not be considered at all. Direct material costs could be considered not applicable because they are relatively fixed on a per-unit basis and and would be required wherever the item was repaired. New training costs and even direct labor costs, adjusted for geographical wage differences, might also be considered inappropriate. Examples of costs which are applicable include: 1) direct labor on products existing in a depot workload, 2) overhead, 3) costs of training new personnel to repair a product already in the workload at another depot, and 4) costs

of transferring workloads to new locations. A measure such as adjusted cost per unit could be effective in making workload cost comparisons but it is difficult to set down exactly what costs are applicable for each workload analysis. For example, the applicable costs for considering the transfer of a product to another depot are different than those for the transfer to industry. Furthermore, cost reports may not distinguish between what we define as applicable and non-applicable costs.

Cost per direct labor hour or standard hour is probably the most frequently used measure in depot workload studies. It does handle the problem of the lack of a homogeneous end product more equitably than cost per unit. Data is usually available for this measure. On the negative side, it is often difficult to relate direct labor hours to depot capacity or output demand. In conducting workload analyses, we are dealing with workload in terms of the number of units demanded of the depot by the field and the number the depot can furnish. Labor hour requirements per unit of output vary depending on time, volume level, experience level and other factors. Thus, the accurate transition from demand to internal depot requirements to output is questionable on a labor hour basis.

The choice of a measure of merit for depot workload analyses should be based on a measure's ability to identify the attainable economical benefits of each potential workload mix and volume level. If our objective is to determine the effects of reducing the workload volume

at a depot, we must answer the question, "What are the cost effects on the remaining workload if we drop product x from the workload?" If our objective is to determine the effects of transferring the repair of an end item to another depot or contractor, we must find not only the economies of scale effects on the depot (or depots) involved but also the effect on total Air Force costs.

The measure presented in this analysis makes use of total cost per unit but does not involve the inequities of comparing unit costs of specific end items. It turns out that the use of total cost per unit or adjusted cost per unit, as discussed earlier, will both have the same results for comparison purposes but adjusted cost per unit will not be as informative as total cost per unit. To make the rationale for the measure more understandable, the hypothesized total unit cost curve will first be discussed.

HYPOTHESIZED COST CURVE

From earlier discussions of the effects of increasing volume level on direct labor, material, and overhead, we would expect that the unit cost curve would resemble that in Figure 23 as volume level increases. An underlying assumption in this figure is that volume level remains within depot capacity in terms of facilities and equipment. Once current capacity level is reached, the cost curve is expected to begin increasing either gradually as in Figure 24 or in steps, depending on the magnitude of the facility/equipment cost necessary to produce one unit beyond capacity.

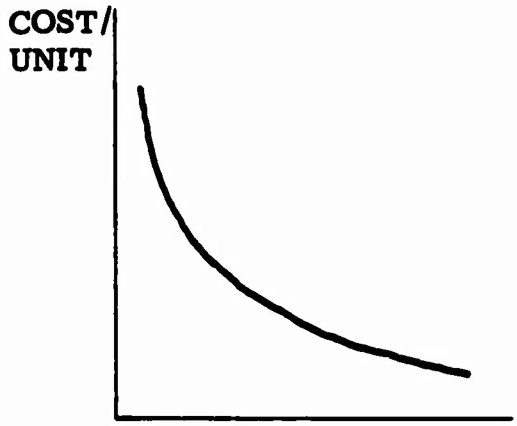

Figure 23
Hypothesized Total Cost/Unit
vs Volume
(Within Capacity)

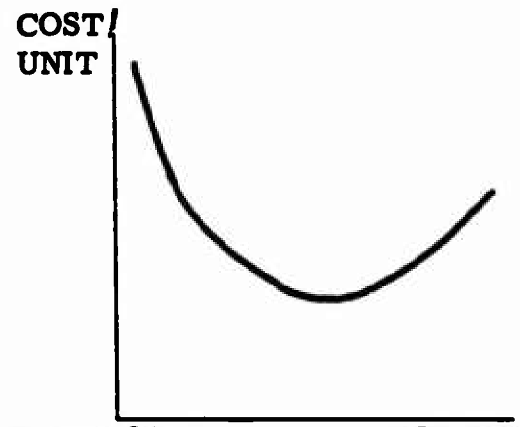

Figure 24
Hypothesized Total Cost/Unit
vs Volume
(Exceeding Capacity)

Although that point was not reached for any of the products in this study, it is also reasonable to expect unit costs to begin rising at some level of volume within capacity. Such factors as complexity of resource management, drop in worker productivity or poor use of limited space may result in diseconomies of scale at some level of production. However, in this analysis of 12 end items at AGMC, the unit cost curves have generally implied a total unit cost curve shaped similar to Figure 23. Given total cost data for each product, a total cost curve can be derived which would represent the weighted average unit cost for some given workload mix at all feasible volume levels. Given individual product cost curves which are generally negative in slope, a total unit cost curve would resemble that in Figure 25 with current production at some volume level q_o and unit cost A.

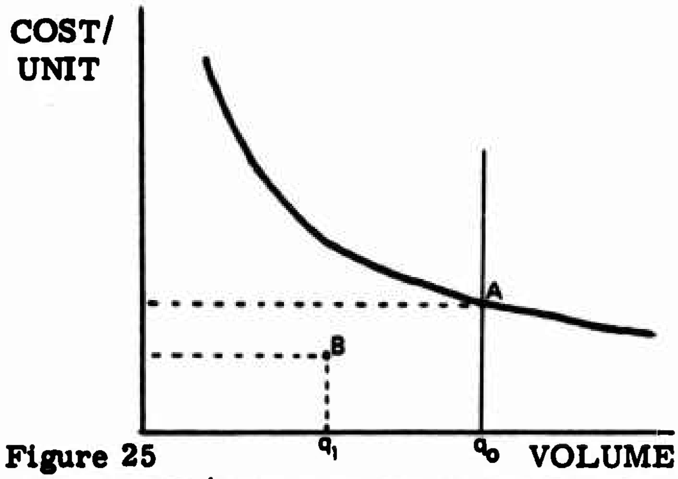

Figure 25
Total Cost/Unit, Current Volume Level

Given current volume level q_0 involving many different products, we can consider the effect on unit cost of dropping a product from the workload at its current volume level. A new total cost per unit (B) can be calculated which would be at some lower volume level (q_1) and either above or below the homogeneous unit cost curve. Similar points can be calculated by dropping each product from the current workload one at a time. A new product could also be added to the current workload, thus moving to a new cost per unit at a volume level above q_0. To do this would require repair cost data on the new product. If repair of the new item closely resembled the type and extent of repair of an existing item, the existing product data could be applied to get an indication of the effects of adding such a new product.

After dropping each product, one at a time, from the current workload, the one which minimizes the total cost per unit can be determined. From the new unit cost point, each remaining product

can be dropped from the workload separately to find the one which minimizes cost per unit with two products removed from the original workload. This procedure can be continued, resulting in a minimum unit cost curve for volume reduction or volume increases as depicted in Figure 26, given a specific set of products with specified volume levels to consider in the analysis. The volume level of each item at q_0 is dictated by demands from the field. If that mix could be realistically altered, the unit cost could possibly be reduced at q_0 as well.

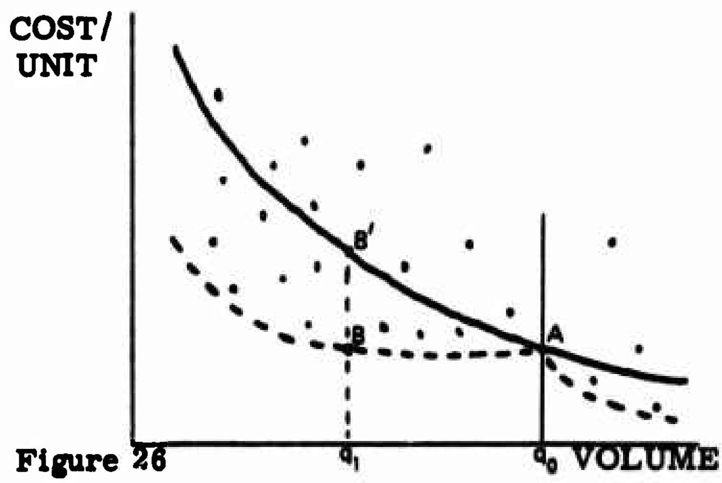

Figure 26
Minimum Unit Cost Curve

COST COMPARISONS

We are now faced with the problem of comparing a potential unit cost point, say B, with the corresponding point on the homogeneous cost curve (B') at the same volume level. Points B and B' are not directly comparable in that each point represents a different workload mix. Point B involves the current workload minus one end item but point B' represents all end items in the current workload but at a reduced volume level for each. Costs of the deleted item must be

dropped from the current workload costs to arrive at a figure which is comparable with the new unit cost point B.

Let C_0 represent the total current costs of a product being deleted from the workload but using the productivity rates of a new product, i.e., using time equal to 1 in the cost estimations but with current prices and salaries. Cost factors indicating a new product should be used for C_0 in order to account for the fact that the item will be new at the new repair location. The benefits of learning and experience will have been lost. Let Q_0 equal the volume level (#units output) of that same product. Let the total costs of the entire current workload, including the product being deleted, be $\sum_{i=0}^{n} C_i$ and the corresponding current volume level be $\sum_{i=0}^{n} Q_i$. The point B' to be compared with B will not necessarily lie on the homogeneous unit cost curve but will be equal to:

$$B' = \frac{\sum_{i=0}^{n} C_i' - C_0}{\sum_{i=0}^{n} Q_i - Q_0}$$

The unit cost point B representing the current workload less one end item will be equal to:

$$B = \frac{\sum_{i=1}^{n} C_i}{\sum_{i=1}^{n} Q_i}$$

where $\sum_{i=1}^{n} C_i$ represents the workload costs with one end item deleted. To understand why B and B' may differ requires a review of how the total costs for each product were derived. For any given end item, direct labor, direct material, and variable overhead costs may differ because of the loss of learning curve benefits at the new source of

repair. Total fixed costs will remain relatively unchanged but each remaining end item must assume a new proportionate share of those fixed costs. With a portion of the workload dropped, all other products must pick up an added share and that share will depend on the new workload mix, in terms of direct labor hours.

If values B and B' are not equal, the difference represents the increase (or decrease) in total cost per unit caused by deleting the end item from the existing workload. We would expect that the new workload unit cost would usually be greater than the revised unit cost in terms of the original mix. That is,

$$\left[\frac{\sum_{i=1}^{n} C_i}{\sum_{i=1}^{n} Q_i}\right] - \left[\frac{\sum_{i=0}^{n} C_i' - C_0}{\sum_{i=0}^{n} Q_i - Q_0}\right] = D \geq O$$

or, since the denominators will be equal,

$$\left[\sum_{i=1}^{n} C_i\right] - \left[\sum_{i=0}^{n} C_i' - C_0\right] \geq O$$

A positive value is expected because the new, reduced workload must now carry all or most of the original fixed costs and the old workload had the benefit of experience in repairing the deleted item. Facility and equipment costs may be very significant in this analysis, and justifiably so if workload deletions or additions leave facilities under-utilized or over-utilized to a great extent. The analyst must take care, however, not to allow sunk costs in facilities and equipment to drive a decision without emphasizing the fact that such savings or costs are not in real dollar terms. The difference, D, represents the added workload unit cost resulting from the elimination of an end item from the workload. Therefore, it is an indication of the maximum

unit cost that DOD should be willing to pay to have the deleted product repaired elsewhere. This is a useful measure to consider especially in cases where a depot is expected to remain in operation but an increase or decrease in the number of end items to be repaired is anticipated. It has the advantage of directly relating input demand to output supply capabilities. In addition, it does not compare specific unit costs of products which are not comparable.

This measure has the disadvantage of creating a somewhat artificial homogeneous product using average costs. A gross measure like average unit cost for all units repaired is only a summary measure of depot operating costs. Thus, the number derived is not of value in and of itself. It must only be used as a point of comparison to estimate the time impact of increasing or decreasing workloads.

The analytical approach discussed here is relatively easy to apply in a computerized economic model. An example of such an analysis, using four of the AGMC end items, will follow.

EXAMPLE

Four end items were chosen from the current AGMC workload. Two began relatively early in AGMC history (LN12, NS17) and two more recently (N16, KT73). The four items represent a wide range of volume levels and a cross-section of repair lines required. The volume levels used for each product in computing the aggregate cost curve are bounded by the lowest and highest volume levels indicated in the historical data. The direct labor hours and all costs repre-

sented in Table VII were derived for each given volume level using the relations presented earlier in this study. All volume levels in this example are assumed to be within depot capacity. The fourth or middle volume level for each end item is approximately the current (Jan. - June 1975) volume level and was used to determine the total volume level and cost per unit.

Three of the end items (LN12, NS17, N16) were aggregated to derive the total cost per unit curve depicted in Figure 27. The current production volume is at point A where LN12 volume is fixed at 175, NS17 at 100 and N16 at 8 units. At that point, total costs (excluding facilities and equipment) are estimated at $2,088,280 for 283 units or $7379 per unit.

The LN12 was then dropped from the workload to derive point B in Figure 27 as follows:

ITEM	#UNITS	DPAH	DL$	DM$	VAR OH	FIXED OH	TOTAL
NS17	100	46600	364450	139940	239490	432150	1176030
N16	8	2205	17440	17900	10980	12260	58580

$$\frac{1234610}{108} = \$11,432 \text{ per unit (Point B)}$$

The high unit cost may indicate that the LN12 is not a good end item to drop first from the current workload.

The NS17 was then dropped from the original workload to find point C as follows:

ITEM	#UNITS	DPAH	DL$	DM$	VAROH	FIXED OH	TOTAL
LN12	175	42040	314810	211840	216870	384040	1127560
N16	8	2205	17440	17900	10980	13190	59510

$$\frac{1187070}{183} = \$6,487 \text{ per unit (Point C)}$$

The N16 data reflects the fact that only the Fixed Overhead cost element changes for an item which remains in the workload.

The N16 was then dropped from the current workload to arrive at point D:

ITEM	#UNITS	DPAH	DL$	DM$	VAR OH	FIXED OH	TOTAL
LN12	175	42040	314810	211840	216870	265390	1008910
NS17	100	46600	364450	139940	239490	288880	1032760

$$\frac{2041670}{275} = \$7,420 \text{ per unit (Point D)}$$

In a similar fashion, costs for the KT73 were added to calculate the increased workload Point E. The new item was entered at an approximate current volume level of 35 units:

ITEM	#UNITS	DPAH	DL$	DM$	VAR OH	FIXED OH	TOTAL
LN12	175	42040	314810	211840	216870	253790	997310
NS17	100	46600	364450	139940	239490	274840	1018720
N16	8	2205	17440	17900	10980	7800	54120
KT73	35	5498	44630	21990	28810	23278	118710

$$\frac{2188860}{318} = \$6,880 \text{ per unit (Point E)}$$

Each of these unit cost figures represents the calculation of:

$$\frac{\sum_{i=1}^{n} C_i}{\sum_{i=1}^{n} Q_i}$$

To determine comparable points on the basis of the original workload, the C_0 costs were calculated for each of the 3 original end items. To account for the loss of learning and experience benefits by moving the end items elsewhere, C_0 was calculated using the average cost per unit

TABLE VII
TOTAL ESTIMATED PRODUCT COSTS PER MONTH
(3 Example End Items Excluding Facilities and Equipment)

Q_i UNITS	DPAH	DL$	DM$	VAR OH$	FOH$	C_i' TOTAL
LN12						
100	36540	277020	173960	246170	252780	949930
125	38370	289600	186600	236290	255690	968180
150	40210	302240	199260	226600	258740	986840
175	42040	314810	211840	216870	261870	1005390
200	43870	327380	224420	207140	265090	1024030
225	45700	339950	237010	197410	268380	1042750
250	47540	352590	249660	187720	271780	1061750
NS17						
70	38490	308640	112060	183730	260010	864440
80	41190	327220	121340	202290	268390	919240
90	43900	345870	130660	220930	276590	974050
100	46600	364450	139940	239490	284620	1028500
110	49300	383030	149220	258060	292500	1082810
120	52010	401670	158540	276690	300310	1137210
130	54710	420250	167820	295260	307960	1191290
N16						
2	2205	17440	17900	5340	8930	49610
4	2205	17440	17900	7220	8610	51170
6	2205	17440	17900	9100	8330	52770
8	2205	17440	17900	10980	8070	54390
10	2205	17440	17900	12860	7840	56040
12	2205	17440	17900	14740	7630	57710
14	2205	17440	17900	16620	7440	59400

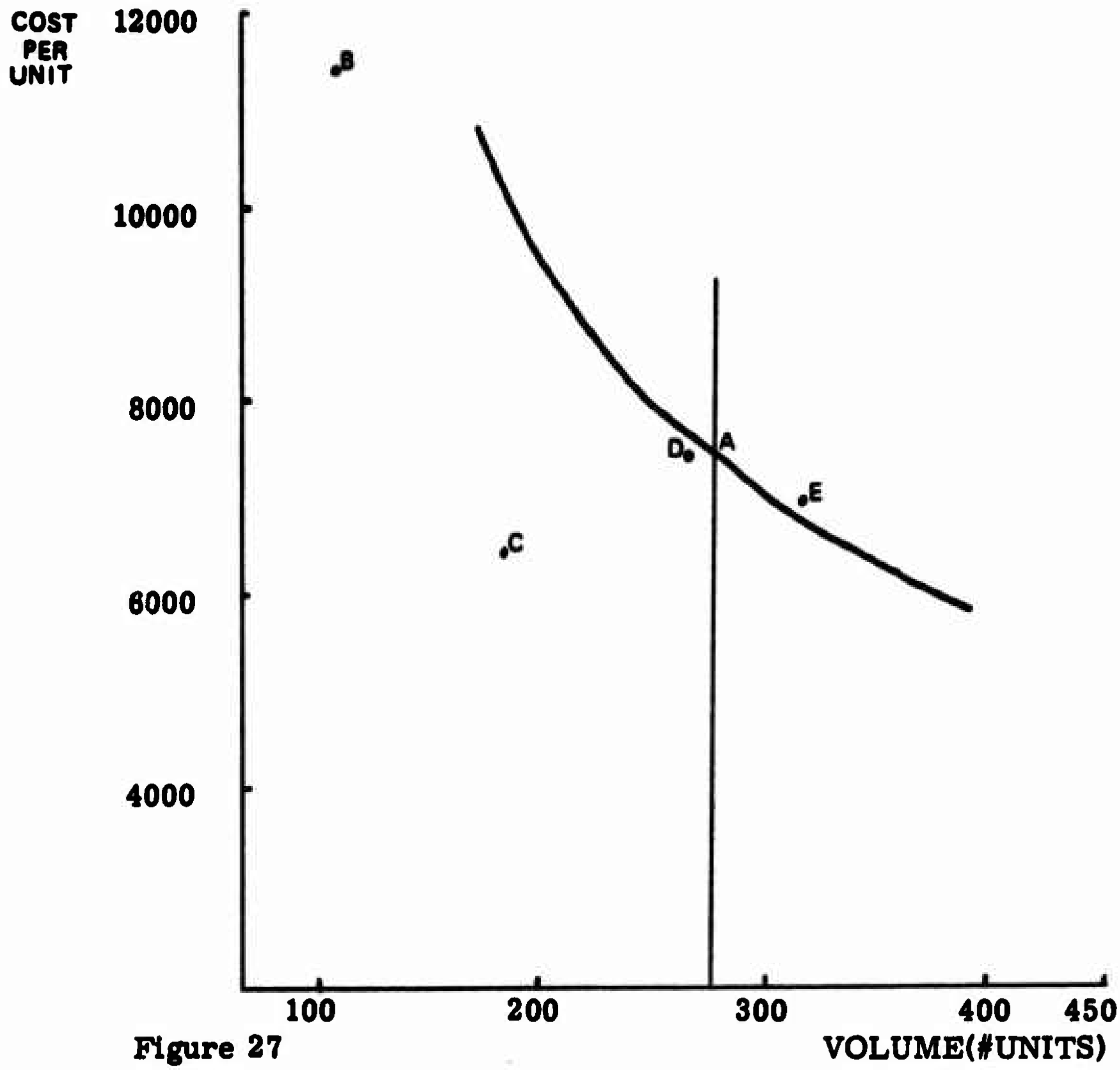

Figure 27
Total Cost Per Unit vs Volume (3 end items)

A. Current volume level, all end items = $7,379

B. Current volume level, all end items except LN-12 = $11,432

C. Current volume level, all end items except NS-17 = $6,487

D. Current volume level, all end items except N-16 = $7,420

E. Current volume level, all end items plus KT-73 = $6,880

incurred during the first year of repair at the depot. Costs were then adjusted up for price changes over time. These costs, then, represent an estimate of the current costs of repairing an item elsewhere.

Current product costs based on the original workload can be taken from Table VII at the appropriate volume level. The adjusted unit cost factor and the difference D can now be derived.

LN12: $$\frac{\sum_{i=0}^{3} C_i' - C_0}{\sum_{i=0}^{3} Q_i - Q_0} = \frac{2088280 - 966190}{283 - 175} = \$10,390$$

$$\left[\frac{\sum_{i=1}^{3} C_i}{\sum_{i=1}^{3} Q_i}\right] - \left[\frac{\sum_{i=0}^{3} C_i' - C_0}{\sum_{i=0}^{3} Q_i - Q_0}\right] = 11,432 - 10,390 = \$1,042$$

NS17: $$\frac{\sum_{i=0}^{3} C_i' - C_0}{\sum_{i=0}^{3} Q_i - Q_0} = \frac{2088280 - 1249970}{283 - 100} = \$4,580$$

$$\left[\frac{\sum_{i=1}^{3} C_i}{\sum_{i=1}^{3} Q_i}\right] - \left[\frac{\sum_{i=0}^{3} C_i' - C_0}{\sum_{i=0}^{3} Q_i - Q_0}\right] = 6,487 - 4,580 = \$1,907$$

N16: $$\frac{\sum_{i=0}^{3} C_i' - C_0}{\sum_{i=0}^{3} Q_i - Q_0} = \frac{2088280 - 16930}{283 - 8} = \$7,532$$

$$\left[\frac{\sum_{i=1}^{3} C_i}{\sum_{i=1}^{3} Q_i}\right] - \left[\frac{\sum_{i=0}^{3} C_i' - C_0}{\sum_{i=0}^{3} Q_i - Q_0}\right] = 7,420 - 7,532 = \$-112$$

In this example, the resulting values of \$1,042 for LN12 and \$1,907 for NS17 were positive as is usually expected and represent a measure of the maximum price that should be paid to have those end items repaired elsewhere. The negative value for the N16 is due in part to the small cost values involved but indicates one of two things: 1) it is advantageous to have the N16 in the existing workload from a cost viewpoint, or 2) fixed costs have not been assigned to the N16 proportionate with its share of the workload.

TRANSFER COSTS

When one alternative is to move the repair of an end item to another depot or to industry, an important consideration is the applicable costs of such a transfer. The total cost of transfer can be difficult to estimate because many types of expenses are involved and each is dependent upon the time, location and extent of transfer. The analytical approach just discussed is just as appropriate for use with transfer costs as it is without. All costs associated with the movement of repair should be considered apart from current normal repair costs. Once estimated on a unit basis, transfer expenses can be added to the repair costs and considered in the workload analysis.

Costs at the new location then become a factor and we face the problem of estimating the new costs of repair for the transferred item. If the transfer is to industry, that estimate is largely given by the contractor and the problem is simplified. If the transfer is to another depot, we face the same estimation problems that exist at the current repair depot. Estimated costs would be different than those at the current depot, however, even if the two depots were identical. The transferred product would be an unfamiliar item at the new depot and the potentially higher unit costs of a new end item would be applicable.

Ideally, the same analytical approach could be applied to both depots to derive estimated costs of repair. With those costs plus the applicable transfer expenses, a new decision measure could be considered--total Air Force unit cost. This measure, if it could be

estimated with reasonable accuracy, may be more useful in decision making than any yet discussed. It involves, however, many assumptions such as equal quality of repair work among depots.

Probably the most demanding aspect yet to be resolved in any of these measures is the estimation of transfer costs. The topic will not be covered in detail here. However, some of the major categories of costs to consider in transferring a product to another government-owned source of repair are presented below.

1. Transferrable capital equipment

    a. Costs of dismantling, packing, shipping, reinstalling equipment.
    b. Costs of altering facilities to accept the transferred equipment.
    c. Costs of damage during shipment
    d. The alternative costs of selling the old equipment and purchasing new equipment for installation.

2. Increase (or decrease) in costs of shipping end items to and from the new location versus the old.

3. Non-transferrable capital

    a. Current value
    b. Costs of converting to other uses
    c. Costs of building required new facilities

4. Personnel

    a. Costs of transferring personnel
    b. Costs of time lost due to personnel transfers
    c. Training costs
    d. Costs of lost productivity

5. Administrative Costs

    a. Costs of planning the transfer
    b. Costs of transferring administrative function - files, equipment, etc.

CHAPTER 8
STUDY LIMITATIONS, AREAS OF FURTHER STUDY

STUDY LIMITATIONS

In this analysis, repair depot costs have been examined in light of changing workloads. Many characteristics of repair costs have been described. On the basis of these characteristics, a recommended approach to the analysis of total depot costs has been presented. Proper use of these results, however, requires the awareness of several limitations and potential pitfalls.

1. While the behavior and trends discussed are valuable with regard to each cost area, some of the estimating relations which were derived are of limited use in a future economic model of AGMC. Some relations, for example, will predict zero or negative costs if extended to a time period much later than the data base. Those functions including a T^2 variable should especially be watched closely. The fit of each relation to the historical data is generally good but the slope depicting future values may be steeper than can realistically be expected. In such cases, the slope should be expected to level off at a realistic range of values rather than continue as indicated. In general, the relations are valid only when independent variables assume values which occurred in the data base.

2. The data base for categories other than direct labor covered a 24-month period in most cases and a 30-month period in others. This is a relatively small data base. However, statistics

maintained since January 1975 are not directly compatible with the previous data base. The addition of more current data to the data base will first require close examination and appropriate adjustments.

3. Potential problems associated with adding up predicted values derived from different relations were not considered in this analysis. Specifically, estimated values may be added but a problem occurs in defining a measure of uncertainty for the total figure. One possible solution is presented by Theil and should be considered in calculating the uncertainty of a total estimate. (Ref 10: 294)

4. The analysis of depot capacity in terms of facilities and equipment was conducted only on a theoretical level. The effects of limited capacity, including surge requirements, should be studied in detail when the analysis considers workloads which approach or exceed capacity.

AREAS OF FURTHER STUDY

1. The data base used in this study should be broadened if possible. It must be remembered, however, that some statistics recorded since January 1975 are not directly compatible with previous data and will require adjustment. With a broadened data base, the cost estimating relations can be improved.

2. Other end items repaired at AGMC should be examined as histories are made available if they represent a significant part of the workload. End items which are not part of the current workload but could potentially be repaired at AGMC should also be examined.

3. In the direct labor area, a detailed examination of the reasons for sporadic behavior in the initial months of repair would be useful. For example, the similarity of a new product with one currently in the workload may be the primary reason for relatively low direct labor requirements in the initial periods.

4. The analysis done on the possible time lag between volume changes and labor hours should be expanded. Such a time delay is expected but was not discovered in this study.

5. A closer look at the effects of depot capacity and surge requirements on potential workload costs is needed. Capacity factors should be in a form that will minimize input requirements for a computerized economic model.

6. Those relations in this study with low R^2 need further examination. A poor fit may be due to erroneous data or changes in the definition of terms. It is also possible that problems occurred in the repair process which caused the unpredictable behavior. It may be that a different variable could be found which will improve some or all of these relations.

7. The area of transfer costs is ripe for study. Some considerations in moving the repair of a product to another depot or to industry were discussed in Chapter 7. An in-depth analysis of all significant costs associated with such a transfer and methods of estimating such costs would be very worthwhile.

8. The analytical approach discussed in Chapter 7 was illustrated but was not performed on a total workload basis. The logical point of departure from this study would be to develop cost estimates for all potential or existing end items of significance and perform a total workload analysis. The approach should be applied in the form of a computerized economic model so that all potential combinations of workloads could be considered.

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Appendix A

Data

DIRECT LABOR HOURS BY MONTH

(Jul 72)	LN12	C5A	LGM25	NS17	LN14	LN7	NS20
1	33146	3882	0918	38107	3863	703	4547
2	40650	3771	9962	40983	4334		7973
3	31076	4398	11842	43383	4029	618	5345
4	35812	2693	13787	43334	5819	222	7180
5	36023	3862	12898	33687	3201	558	7167
6	37181	1783	10197	45426	4390	135	7316
7	48537	1730	13400	46972	3007	903	10820
8	33306	5319	10683	31132	2695	267	8995
9	18224	6670	12505	47725	3581	475	9271
10	32138	4086	13158	36794	4717	193	9186
11	29370	4638	11753	44323	3801	322	7323
12	23382	3700	15595	38452	4087	242	10392
13	22595	3327	9398	34366	5638	360	7817
14	26847	7025	12504	37745	6068	541	10147
15	23390	4581	11480	36500	4663	94	8280
16	22171	4377	9895	45257	4104	295	8218
17	23065	4787	10795	35503	4152	70	12940
18	23576	6094	10395	31659	4240	446	9662
19	27223	6228	15385	40124	4531	637	13873
20	24408	4880	-	39530	5866	180	13184
21	21746	4332	11592	38344	3456	392	11003

DIRECT LABOR HOURS

	LN12	C5A	LGM25	NS17	LN14	LN7	NS20
22	26936	4821	9120	41665	6674	298	13043
23	24679	5845	8373	37142	4049	91	12867
24	19412	3553	17321	31422	19614	169	13033
25	26317	5846	13319	43634	4650	343	13138
26	28559	9656	10905	28247	3924	158	14020
27	27246	5616	14019	35988	5805	141	13763
28	29375	5771	17487	29241	2552	376	16525
29	27533	3115	9984	30000	2181	542	15636
30	13214	4714	5359	24133	1608	0	9994

DIRECT LABOR HOURS BY MONTH

(Jul 72)	N16	KT71	NS10	KT73	SR3	7900D
1	1644	2599	6324	4642		
2	1180	1930	6831	6360		
3	2346	345	6971	5985		
4	3188	-	5587	9345		
5	1586	787	6144	8556		
6	2394	1140	4939	6192		
7	1197	1924	4634	9786		
8	2102	1034	2426	6721		
9	2572	1021	3934	6018		
10	818	740	2147	6059		
11	1604	9	2152	8961		
12	1861	597	2587	9017		
13	2130	1162	3006	7614		
14	2482	860	2625	8654		
15	2204	641	2806	7619	452	
16	1619	679	584	6952	3416	
17	2028	1030	590	5860	3362	
18	1695	665		6461	2174	159
19	2624	607		6700	2038	
20	1918	799		6636	1598	253
21	2347	1058		6320	1474	1001

DIRECT LABOR HOURS

	N16	KT71	NS10	KT73	SR3	7900D
22	2070	1151		6253	2346	440
23	2391	1426		7335	2361	117
24	2633	926		6566	1683	656
25	2237	1508		6751	1061	1571
26	1894	846		5572	1235	1027
27	3089	659		5767	749	868
28	2610	808		7065	1240	1719
29	895	1339		7182	1254	2153
30	1757	768		3488	1057	1809

DIRECT LABOR HOURS
BY MONTH

(Jul 72)	T38	2171AB	2171W	G200FG	N16GY
1				10464	2593
2				9374	2406
3				13542	1466
4				8414	2636
5				7224	2441
6				10180	1816
7				10749	2602
8				13259	939
9				25765	1509
10				14058	2788
11				16742	1943
12				20046	2001
13				26954	1444
14				11883	2223
15	914			20711	1286
16	3357	5696		19588	1183
17	5156	6281	921	17866	1019
18	3211	12306	1718	14677	1216
19	4548	16429	2787	8364	1006
20	3413	12242	2669	13986	1236
21	3506	12782	3795	13004	17

DIRECT LABOR HOURS

	T38	2171AB	2171W	G200FG	N16GY
22	5531	11239	3510	14563	1438
23	5256	11604	14069	12572	1345
24	3735	9611	2837	10127	1024
25	3616	10762	3116	9885	1602
26	5592	10703	2598	9986	1613
27	4645	7409	3305	9954	1903
28	4924	10078	3064	10616	1348
29	4624	8715	2620	9412	1557
30	2961	6371	2043	8614	957

TOTAL DIRECT LABOR HOURS
(DPAH)
ALL END ITEMS (18) BY MONTH

(Jul 72)	1	121532	16	137391
	2	135754	17	135424
	3	131346	18	130354
	4	138017	19	153104
	5	124134	20	132798
	6	132989	21	136169
	7	156261	22	151098
	8	118878	23	151522
	9	139270	24	144322
	10	126882	25	150614
	11	132941	26	137807
	12	131959	27	141408
	13	125811	28	146135
	14	129604	29	128996
	15	125621	30	88847

UNITS PRODUCED BY MONTH

(Jul 72)	LN12	C5A	LGM25	NS17	LN14	LN7	NS20
1	187	10	10	98	34	2	18
2	187	13	13	92	32	3	21
3	187	10	13	85	32	2	19
4	204	8	11	98	27	2	27
5	204	10	11	80	23	2	38
6	196	4	9	100	25	1	34
7	204	6	11	102	25	2	34
8	157	9	8	102	24	2	36
9	157	11	11	108	26	2	28
10	173	10	12	86	35	2	33
11	172	9	11	113	35	2	27
12	172	12	13	89	35	2	40
13	157	10	12	80	45	2	32
14	157	11	12	88	39	1	35
15	156	12	9	91	27	1	27
16	171	13	10	99	22	2	20
17	171	16	9	76	26	1	24
18	172	16	6	81	26	1	27
19	171	12	12	91	25	2	30
20	167	11	-	78	25	1	33

UNITS PRODUCED

	LN12	C5A	LGM25	NS17	LN14	LN7	NS20
21	176	11	18	91	26	1	34
22	177	12	15	89	26	2	42
23	188	11	18	97	25	1	42
24	200	7	10	85	25	1	38
25	205	11	13	87	24	2	38
26	191	18	13	76	24	2	35
27	173	14	12	76	22	1	33
28	169	16	12	77	17	3	26
29	177	13	13	71	16	5	29
30	114	12	5	65	14		20

UNITS PRODUCED BY MONTH

(Jul 72)	N16	KT71	NS10	KT73	SR3	7900D
1	7	7	17	20		
2	4	4	6	24		
3	6	2	26	24		
4	5	-	15	26		
5	4	3	9	27		
6	7	4	8	24		
7	3	4	11	28		
8	6	3	5	28		
9	8	3	7	31		
10	3	4	5	30		
11	5		4	41		
12	3	2	4	41		
13	8	3	5	41		
14	5	3	4	45		
15	5	4	5	41	2	
16	8	4	3	39	25	
17	8	4	4	41	24	
18	8	3		36	28	
19	8	4		40	19	
20	8	4		31	12	3

UNITS PRODUCED

	N16	KT71	NS10	KT73	SR3	7900D
21	8	6		32	24	7
22	11	5		34	23	4
23	12	6		55	25	1
24	10	6		67	29	7
25	11	10		50	19	16
26	10	6		47	19	10
27	10	6		44	11	10
28	10	5		45	19	19
29	5	6		41	20	25
30	7	3		15	13	20

UNITS PRODUCED
BY MONTH

(Jul 72)	T38	2171AB	2171W	G200FG	N16GY
1				80	20
2				80	20
3				80	20
4				80	20
5				81	20
6				80	20
7				100	26
8				100	12
9				110	12
10				88	23
11					17
12				263	27
13				123	18
14				62	18
15	5			131	16
16	29	60		126	16
17	52	67	10	117	19
18	58	207	18	93	23
19	51	280	42	48	16
20	28	226	34	69	24

UNITS PRODUCED

	T38	2171AB	2171W	G200FG	N16GY
21	60	220	47	89	35
22	49	230	49	101	20
23	60	224	46	107	30
24	60	224	46	105	30
25	62	240	49	302	41
26	87	230	39	295	45
27	81	169	53	250	42
28	81	240	51	279	44
29	80	216	48	264	53
30	42	147	35	200	32

DIRECT MATERIAL
BY MONTH

(Jul 72)	LN12	C5A	LGM25	NS17	LN14	LN7
1	133176	10265	14566	95656	6750	206
2	131291	10626	26455	113770	28868	
3	99697	16505	21059	153029	17932	977
4	142588	7290	26811	135308	65077	832
5	154832	9056	23846	128757	11425	472
6	144617	4351	14679	214077	32343	315
7	217226	19479	20119	221586	13159	571
8	133210	19066	20514	144213	1313	181
9	49515	17816	22968	238150	7255	217
10	125463	24230	28237	198044	35319	533
11	113726	27404	28765	219343	25755	602
12	70246	15490	36638	178572	31662	141
13	64700	8042	20081	128995	29523	37
14	75561	21571	22889	137464	16845	
15	57608	11535	24866	146327	47103	224
16	52313	14970	13629	200533	45147	20
17	96665	18186	27808	149641	37900	35
18	74438	16367	20570	153869	24199	345
19	133641	7757	30527	161658	12714	
20	101578	6763	-	158601	23027	103

DIRECT MATERIAL

	LN12	C5A	LGM25	NS17	LN14	LN7
21	101143	8001	22012	187963	4847	146
22	111382	9920	25645	204602	15681	
23	92865	13022	21788	165680	7837	
24	50522	12683	42059	112239	13062	22
25	126661	24167	27628	221911	9032	60
26	135036	21752	28010	213520	6409	754
27	112588	11781	30100	184718	16063	1247
28	148661	11384	31008	135528	1638	92
29	156027	5820	14752	133496	3488	77
30	53296	24401	13535	140959	2996	

DIRECT MATERIAL
BY MONTH

(Jul 72)	NS20	N16	KT71	NS10	KT73	SR3
1	22062	3894	15714	6920	3468	
2	26445	2660	5796	10231	4704	
3	31409	15435	2820	9674	5671	
4	27104	17709	–	6258	7164	
5	38161	2324	5411	5295	7601	
6	50663	1793	2906	6175	1691	
7	43150	4995	12023	3409	8546	
8	24159	6244	10734	1642	3818	
9	39131	11029	3498	5752	3189	
10	20903	1971	1155	4418	4452	
11	31121	3503		2235	7594	
12	20218	7865	2738	2308	5904	
13	14231	4229	1892	4609	3941	
14	17844	6454	1163	3169	2745	
15	21489	7889	1671	2866	2713	6472
16	17904	6938	54	589	3442	7329
17	26937	7318	8910	560	5383	16443
18	23682	7101	617		6908	10731
19	30236	8483	394		7445	11761
20	34260	12632	470		8369	26933
21	21221	13059	500		7264	36883

DIRECT MATERIAL

	NS20	N16	KT71	NS10	KT73	SR3
22	30210	8097	1900		31398	17399
23	28471	11350	1694		14326	13501
24	31836	7871	10482		14405	3184
25	30982	7199	1614		6148	6563
26	18819	10853	308		18960	9338
27	34469	15173	173		11239	12268
28	36548	15254	137		19109	6982
29	35836	5839	661		28303	6222
30	38329	8761	16		11809	5368

DIRECT MATERIAL
BY MONTH

(Jul 72)	7900D	T38	2171AB	2171W	G200FG	N16GY
1					41566	8409
2					37463	16495
3					52536	4031
4					57792	5179
5					23121	2496
6					30390	2955
7					29527	7505
8					49607	3607
9					137914	4336
10					58418	10993
11					57079	4028
12					57030	4435
13					39924	3362
14					29712	6632
15		41995			47085	4057
16		11422	32672		59966	1537
17		16064	36575	12713	50421	3561
18		9921	17863	11149	46418	4906
19		10389	35569	7858	38056	6729
20	61107	20918	49194	16677	13881	7576
21	50174	11892	52714	12368	38968	

DIRECT MATERIAL

	7900D	T38	2171AB	2171W	G200FG	N16GY
22	5110	6999	39598	21290	58453	9864
23	26422	6387	23376	3613	45438	6941
24	8906	6302	22156	7121	24084	6835
25	25734	10699	52042	5868	40368	13554
26	17637	21508	50387	18195	39191	25172
27	47577	5717	30128	7523	50729	12641
28	12975	12416	43035	3703	57236	10677
29	29835	14137	25288	2433	54201	17424
30	746	8153	33783	1983	47698	16956

VARIABLE OVERHEAD
BY MONTH

(Jul 72)	LN12	C5A	LGM25	NS17	LN14	LN7	NS20
1	156524	27842	42737	221718	17181	4659	25792
2	158862	27101	40225	207745	17143		40659
3	101166	35703	49990	203138	13687	2861	22870
4	122048	22605	59331	189720	22011	657	32179
5	117576	29306	52865	153213	10332	2147	31435
6	124827	13719	38809	196381	15225	501	30363
7	160978	13247	52415	201563	10611	4833	45420
8	123601	39522	42757	132188	11200	1092	38896
9	81417	50544	45587	222548	17885	2230	41965
10	127661	30656	51844	171233	20954	913	38949
11	105842	36177	43178	203311	12601	1026	34060
12	101104	25048	64714	176434	15113	871	46181
13	88142	22605	41136	153838	20025	1116	33659
14	105980	59047	51036	166337	22209	2019	44293
15	93963	40217	43616	161452	19550	341	35827
16	83528	33123	43279	196132	15692	984	35161
17	92222	34321	50222	156430	17222	286	51163
18	85777	38595	48863	143396	15772	1644	39703
19	98088	38114	69341	180657	16856	2160	55062
20	86546	34918	–	178732	20626	743	54554

VARIABLE OVERHEAD

	LN12	C5A	LGM25	NS17	LN14	LN7	NS20
21	83180	27902	55560	175737	12993	1557	46104
22	122380	31984	44450	190065	23346	1165	54633
23	94206	35549	45866	184616	16106	400	52674
24	78538	23731	84399	153654	22724	534	60233
25	104925	38478	63816	214282	17366	1359	63530
26	112105	65121	56706	138665	16394	742	58367
27	104837	34777	68664	181318	20591	582	67832
28	111072	35755	89630	144494	9442	1374	82042
29	112373	20462	55012	149970	8308	2148	66377
30	51205	31882	27451	124723	6040		50121

VARIABLE OVERHEAD
BY MONTH

(Jul 72)	N16	KT71	NS10	KT73	SR3	7900D
1	12459	12081	35351	19672		
2	8186	9792	32469	31329		
3	20097	1244	32418	23567		
4	22443	–	26003	37274		
5	12176	4001	28236	31166		
6	24164	5355	21492	26229		
7	11505	9493	20795	49915		
8	23925	4508	10906	33028		
9	28010	5320	18420	29810		
10	7917	6654	11431	21149		
11	12244	170	10858	63136		
12	14319	4108	13374	58379		
13	17730	6105	16506	38399		
14	19544	4825	13944	40449		
15	17303	3075	13783	36942	19139	
16	13699	2427	3153	30209	15590	
17	18389	3784	3281	21189	10240	
18	13918	2383		24845	8738	936
19	21355	2123		24906	4784	
20	13634	3342		25115	4723	510

VARIABLE OVERHEAD

	N16	KT71	NS10	KT73	SR3	7900D
21	14418	5982		34613	4927	2185
22	14679	6678		36222	5274	1392
23	17013	9818		38481	5811	339
24	20869	4469		36135	7285	1707
25	13507	7059		32676	2839	4162
26	11569	4481		29688	2867	2339
27	18452	2993		28135	2153	2493
28	16300	4558		37243	3340	4617
29	6487	6630		36149	3489	5999
30	11755	3377		16099	2740	4687

VARIABLE OVERHEAD BY MONTH

(Jul 72)	T38	2171AB	2171W	G200FG	N16GY
1				56764	14087
2				43785	10847
3				56034	6096
4				41817	11573
5				23522	9772
6				31354	7428
7				33306	12594
8				38206	4262
9				85096	7117
10				47558	12270
11				53917	8602
12				69577	10202
13				65766	7842
14				45709	11540
15	33871			86425	10360
16	15327	26352		77149	7916
17	15877	19703	2713	66604	6405
18	13069	36838	5187	49344	11685
19	10707	30805	5202	28194	4522
20	10137	24692	5374	29725	3001

VARIABLE OVERHEAD

	T38	2171AB	2171W	G200FG	N16GY
21	11729	28208	8381	41433	81
22	12484	35266	11004	45137	11750
23	13210	32250	10375	39190	9864
24	16171	25220	7430	32865	6300
25	9741	28678	8285	32398	8872
26	12897	24517	5956	31188	9989
27	13383	21298	9522	33259	10637
28	13360	27505	8160	37187	8513
29	12999	24295	7297	34427	11917
30	7738	16708	5260	32665	6795

FIXED OVERHEAD
BY MONTH

(Jul 72)	LN12	C5A	LGM25	NS17	LN14	LN7	NS20
1	109478	9807	19880	131561	15526	1777	15762
2	142980	10405	23641	148499	15238		28119
3	120411	10960	30050	151630	13873	2022	17901
4	145421	7189	32898	159755	19803	787	26914
5	151645	9841	32337	126070	11874	1963	25922
6	148086	4092	22259	163327	16898	514	25883
7	189272	3076	30387	170730	10727	2617	39244
8	128832	10477	26507	120207	9328	942	35155
9	71153	14006	31092	181169	13295	1815	34871
10	139943	8722	35004	132375	19311	851	32691
11	121197	11790	33510	167140	15642	1166	27502
12	96194	10328	43540	143571	17249	1041	39474
13	103680	9111	30144	133445	27229	1682	31123
14	133979	19480	37191	161660	30868	2496	43090
15	120386	15121	37749	155550	22680	475	33833
16	114472	16785	31848	185600	20951	1445	34626
17	129444	15797	35512	145167	24270	467	52000
18	117495	20696	34778	126983	21657	2112	38065
19	127985	18464	51778	151249	22606	3103	52608
20	124569	14753	–	153126	29663	1052	49904

FIXED OVERHEAD

	LN12	C5A	LGM25	NS17	LN14	LN7	NS20
21	99612	12959	43085	148652	16838	1662	44199
22	107613	12672	30911	155897	30704	1461	50378
23	123342	14818	30041	150876	20569	509	49956
24	118722	9427	59953	133621	30929	720	58020
25	127262	17329	48034	176073	23058	154	54131
26	137290	28355	38261	110615	28985	820	47998
27	137294	18822	48690	144312	28772	712	54981
28	143489	21526	59756	118471	12230	1724	66806
29	150553	14077	35099	125511	11485	2975	56995
30	78354	20579	18800	113076	8939		44965

FIXED OVERHEAD BY MONTH

(Jul 72)	N16	KT71	NS10	KT73	SR3	7900D
1	2649	6082	20711	9464		
2	1940	4088	21058	12134		
3	4218	745	21368	12656		
4	5336	–	17969	18103		
5	1830	1678	17206	18906		
6	3280	2086	13712	12372		
7	1799	4225	13546	21893		
8	4090	2515	6954	17098		
9	5952	2478	11251	14697		
10	1709	2467	6165	20168		
11	3620	22	6172	30158		
12	3596	1690	7559	26602		
13	5353	3493	9188	24321		
14	6993	2897	8102	29840		
15	7239	2150	9573	24937	1019	
16	5932	2372	2045	23644	7262	
17	7025	3607	2169	20596	7698	
18	5157	2017		20073	8231	
19	8737	2028		22098	4847	
20	8653	2759		22633	3720	911
21	9032	3447		20374	4998	3011

FIXED OVERHEAD

	N16	KT71	NS10	KT73	SR3	7900D
22	6260	3880		20653	4967	1401
23	9254	5787		29399	6554	412
24	11875	4695		30489	6573	3160
25	8986	6024		27839	4089	6050
26	6798	3338		22263	4390	3637
27	11922	2943		25182	3320	3845
28	10310	2889		27141	5128	7114
29	4560	5161		27707	6056	10435
30	10511	2786		13188	4976	8511

FIXED OVERHEAD
BY MONTH

(Jul 72)	T38	2171AB	2171W	G200FG	N16GY
1				25429	4951
2				28894	5078
3				48169	4431
4				44701	5519
5				30687	4276
6				42040	3425
7				45124	5826
8				50855	2287
9				108047	3300
10				62169	7227
11				72624	5401
12				89524	5918
13				88275	4580
14				57873	7056
15	1937			106250	4525
16	7849	10220		98051	4224
17	11253	11985	2288	91702	4730
18	12093	28335	3972	69153	5467
19	10844	41617	7069	37551	4421
20	8002	43766	9602	46398	6532
21	14149	37609	11103	59416	62

FIXED OVERHEAD
BY MONTH

	T38	2171AB	2171W	G200FG	N16GY
22	11737	35737	11143	63221	6093
23	14672	40050	9427	58361	5797
24	14570	45881	13414	54284	5687
25	13916	41459	12025	49957	6330
26	19821	37802	9205	47599	5696
27	20593	32812	14655	49728	7147
28	20414	41890	12678	54016	5450
29	22456	41709	12743	49791	8641
30	13948	29989	9589	47635	6291

GENERAL AND ADMINISTRATIVE EXPENSES BY MONTH

(Jul 72)	LN12	C5A	LGM25	NS17	LN14	LN7	NS20
1	19735	1802	3562	20083	2587	550	2232
2	16517	1072	3307	14756	1363		2817
3	11621	1467	3779	15191	1549	315	1853
4	15040	765	4064	16377	2324	76	2704
5	14838	1030	3635	12404	1173	266	2514
6	15707	430	2769	14377	1797	58	2808
7	19374	315	3800	17509	1069	558	3982
8	14908	1339	3407	13833	1203	117	4131
9	7830	1717	3604	19908	1479	232	3855
10	15067	954	4022	14327	2325	24	3570
11	13348	1229	3446	17337	1573	141	2843
12	10224	1102	5057	15312	1886	111	4210
13	10644	937	3094	13801	2736	173	3195
14	12067	2019	4003	14860	2718	102	3878
15	11964	1518	3859	15461	2524	52	3459
16	10911	1651	3173	17980	1992	140	3373
17	11885	1546	3457	13635	2247	42	4927
18	12200	2053	3515	12795	2275	219	3977
19	13807	1921	5409	16068	2417	313	5609
20	13257	1571	-	16264	3120	106	5285
21	10462	1376	4514	15679	1757	201	4648

GENERAL AND ADMINISTRATIVE EXPENSES

	LN12	C5A	LGM25	NS17	LN14	LN7	NS20
22	11056	1349	3284	16909	3291	152	5468
23	12365	1545	3091	15206	2065	50	5127
24	10561	911	6045	12644	2731	75	5436
25	12958	1730	4739	17708	2352	160	5481
26	14181	2931	3914	11319	1971	86	5000
27	13962	1919	5164	14612	2928	74	5573
28	14391	2174	6427	11850	1229	175	6707
29	14459	1364	3432	12247	1120	286	5539
30	8463	2143	1874	11892	943		4675

GENERAL AND ADMINISTRATIVE EXPENSES BY MONTH

(Jul 72)	N16	KT71	NS10	KT73	SR3	7900D
1	378	1054	3352	1548		
2	112	472	2227	1080		
3	385	74	2509	1256		
4	709	-	1849	2002		
5	175	197	1652	1895		
6	354	232	1422	1360		
7	183	461	1362	2225		
8	607	293	801	2061		
9	663	282	1234	1576		
10	182	266	660	2202		
11	371	4	642	3041		
12	390	215	831	2891		
13	553	361	977	2468		
14	649	246	783	2563		
15	730	234	928	2616	111	
16	557	220	200	2228	676	
17	655	329	200	1857	692	
18	523	226		2163	935	
19	935	226		2458	542	
20	932	290		2400	396	97
21	961	360		2125	626	315

GENERAL AND ADMINISTRATIVE EXPENSES

	N16	KT71	NS10	KT73	SR3	7900D
22	691	432		2299	561	158
23	939	518		2927	631	40
24	1104	419		2744	567	272
25	906	628		2846	439	650
26	702	352		2309	462	383
27	1203	301		2553	336	389
28	1033	287		2704	507	704
29	435	488		2657	564	971
30	1125	309		1428	568	972

GENERAL AND ADMINISTRATIVE EXPENSES BY MONTH

(Jul 72)	T38	2171AB	2171W	G200FG	N16GY
1				5848	744
2				4529	323
3				5872	479
4				4906	586
5				2976	420
6				4395	337
7				4529	582
8				5949	283
9				12030	356
10				6717	776
11				7515	551
12				9448	638
13				9226	471
14				5693	646
15	211			10413	461
16	730	951		9474	407
17	1011	1076	205	8668	428
18	1373	3225	451	6882	574
19	1214	4664	792	3882	487
20	852	4667	1023	4632	704
21	1477	3928	1159	6189	6

GENERAL AND ADMINISTRATIVE EXPENSES

	T38	2171AB	2171W	G200FG	N16GY
22	1324	4027	1256	6825	670
23	1415	3853	1109	5941	584
24	1257	2958	1161	5073	506
25	1495	4448	1292	4857	643
26	2085	3976	969	4881	587
27	2086	3325	1485	5086	730
28	2021	4153	1255	5451	542
29	2092	3898	1187	4845	815
30	1593	3386	1092	4894	669

TOTAL FIXED OVERHEAD
AND G&A
ALL END ITEMS BY MONTH

(Jul 72)	TFOH	TG&A	TOTAL COMBINED FOH, G&A
1	373077	63475	436552
2	442074	48575	490649
3	438434	46350	484784
4	484395	51402	535797
5	434235	43175	477410
6	457974	46046	504020
7	538466	55949	594415
8	415247	48932	464179
9	493126	54766	547892
10	468802	51092	519894
11	495944	52041	547985
12	486286	52315	538601
13	471624	48636	520260
14	541525	50227	591752
15	543424	54541	597965
16	567326	54663	621989
17	565710	52860	618570
18	516999	53386	570385
19	567005	60754	627759
20	543048	55596	598644

TOTAL FIXED OVERHEAD AND G&A ALL END ITEMS BY MONTH

	TFOH	TG&A	TOTAL COMBINED FOH, G&A
21	530208	55783	585991
22	554728	59752	614480
23	569824	57406	627230
24	602020	55464	657484
25	622716	63332	686048
26	552873	56108	608981
27	605730	61726	667456
28	611032	61610	672642
29	585954	56399	642353
30	432137	46026	478163

WHOLESALE PRICE INDEX

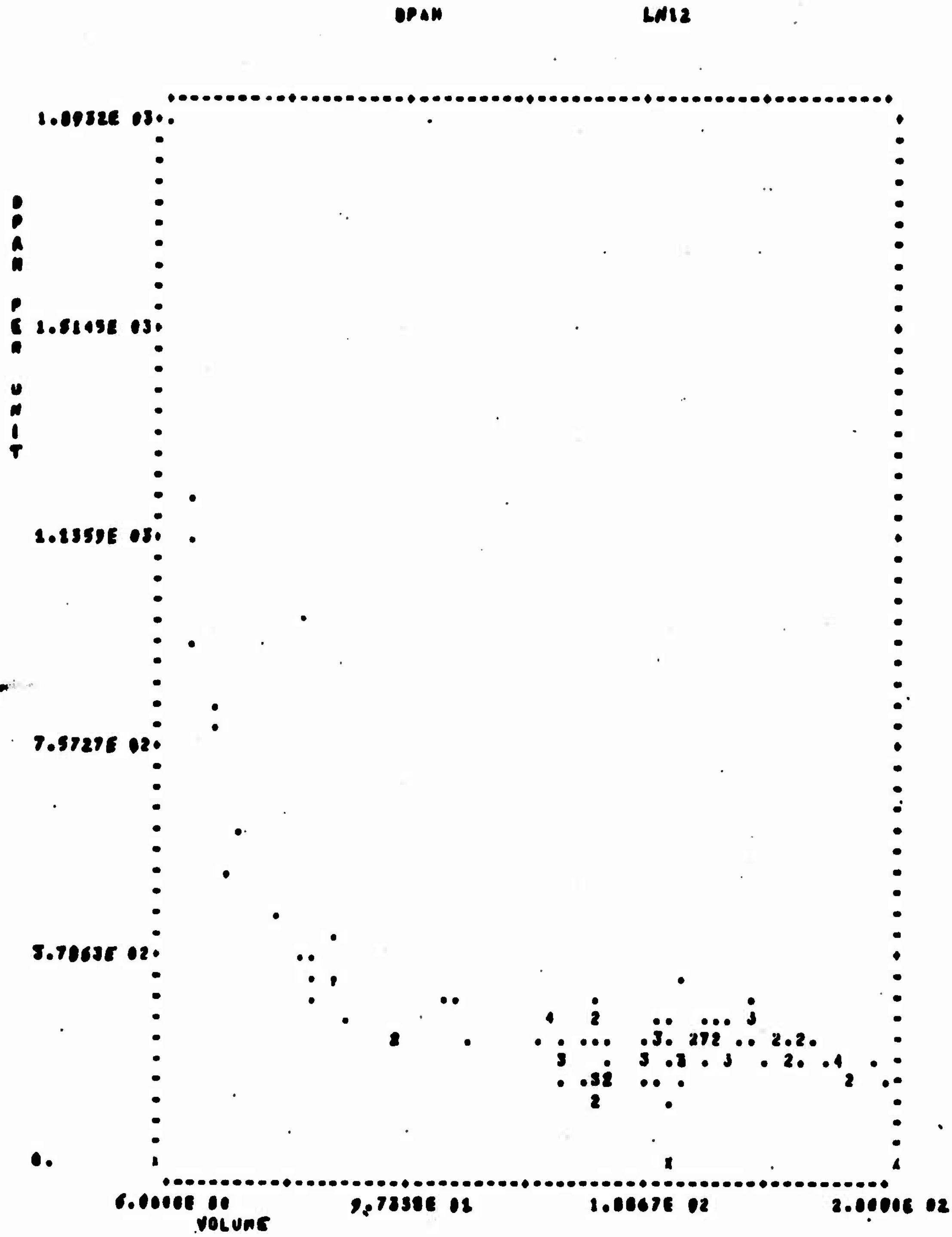
June 72	119.0	Dec. 73	134.8
July 72	119.2	Jan. 74	137.9
Aug. 72	119.5	Feb. 74	140.6
Sept. 72	119.8	Mar. 74	145.8
Oct. 72	120.1	April 74	150.8
Nov. 72	120.3	May 74	156.1
Dec. 72	120.5	June 74	159.6
Jan. 73	121.2	July 74	161.7
Feb. 73	122.6	Aug. 74	167.4
Mar. 73	124.8	Sept. 74	167.2
April 73	126.6	Oct. 74	170.2
May 73	128.0	Nov. 74	171.9
June 73	128.6	Dec. 74	171.5
July 73	128.5	Jan. 75	171.8
Aug. 73	129.3	Feb. 75	171.3
Sept. 73	130.1	Mar. 75	170.4
Oct. 73	131.0	April 75	172.1
Nov. 73	132.4	May 75	173.2
		June 75	173.7

GSAL INDEX
(Average GS Level Salaries)

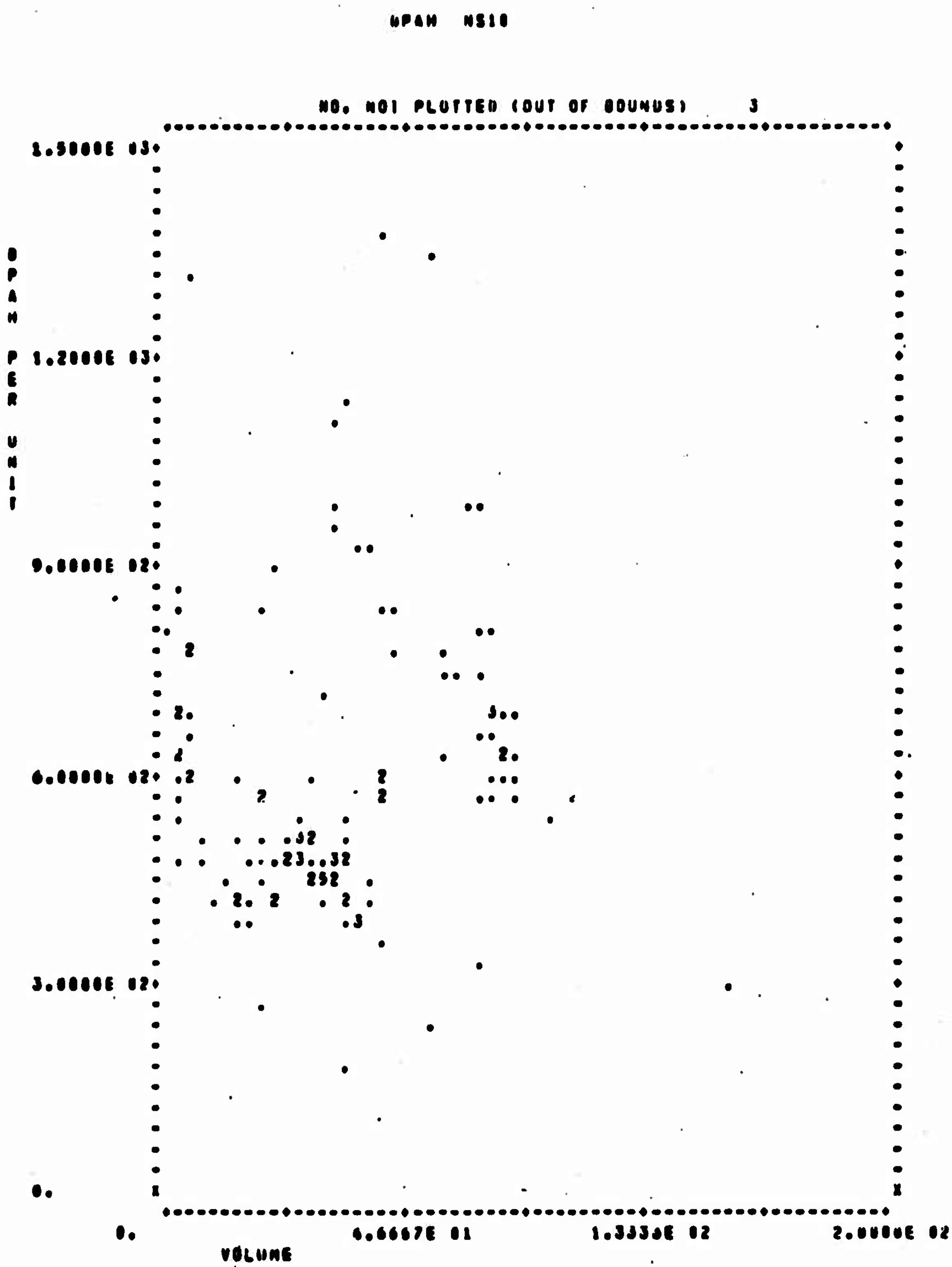
July 72	11530.5	July 73	12202.5
Aug. 72	11370.5	Aug. 73	12245.2
Sept. 72	11585.5	Sept. 73	12360.3
Oct. 72	11650.5	Oct. 73	12942.4
Nov. 72	11659.8	Nov. 73	12933.8
Dec. 72	11653.0	Dec. 73	12903.0
Jan. 73	12329.0	Jan. 74	12905.2
Feb. 73	12354.5	Feb. 74	12903.0
Mar. 73	12347.8	Mar. 74	12893.5
April 73	12424.9	April 74	12890.7
May 73	12418.5	May 74	12886.0
June 73	12215.5	June 74	12862.0

Appendix B

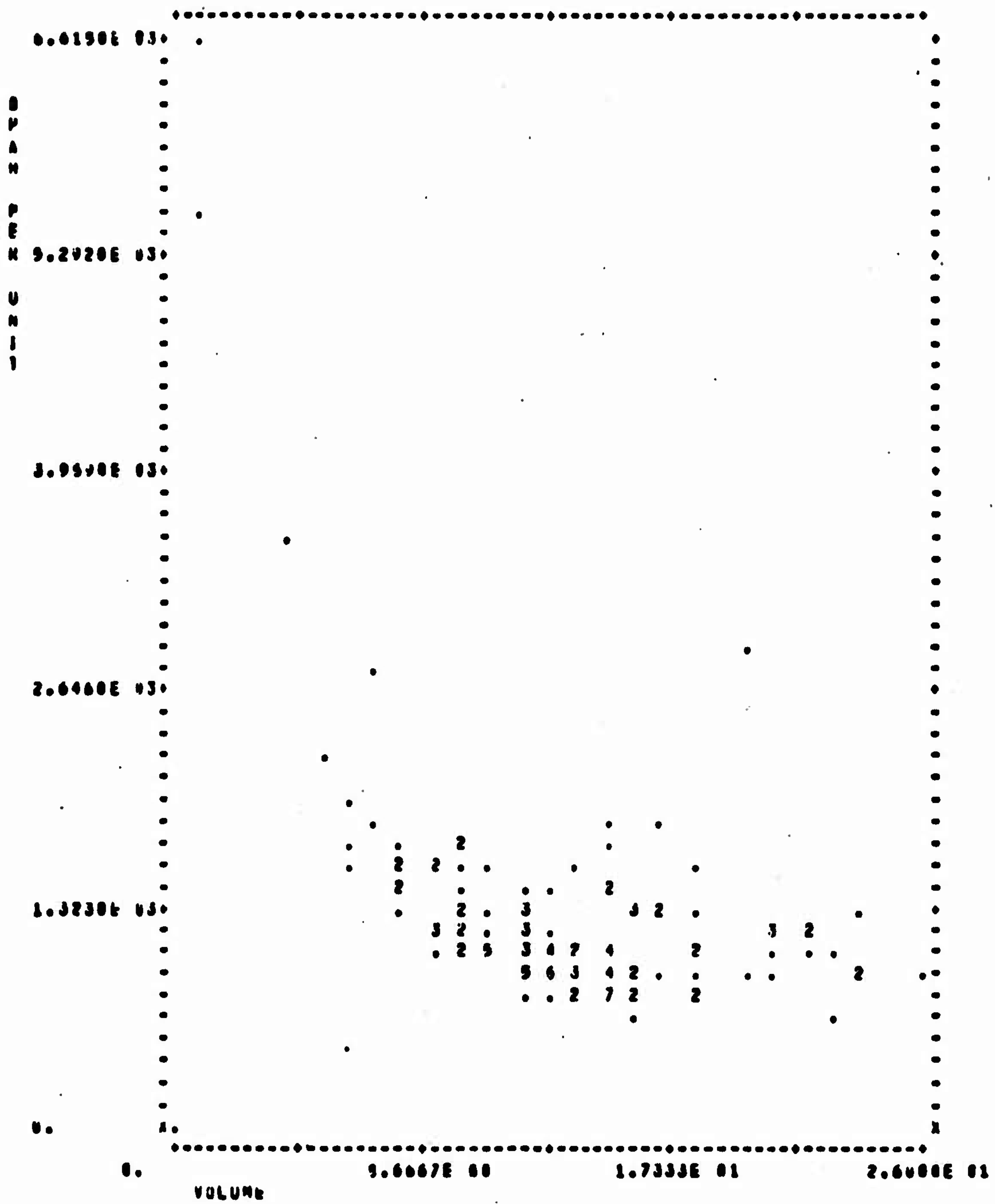
Graphs of Direct Labor Hours vs Volume



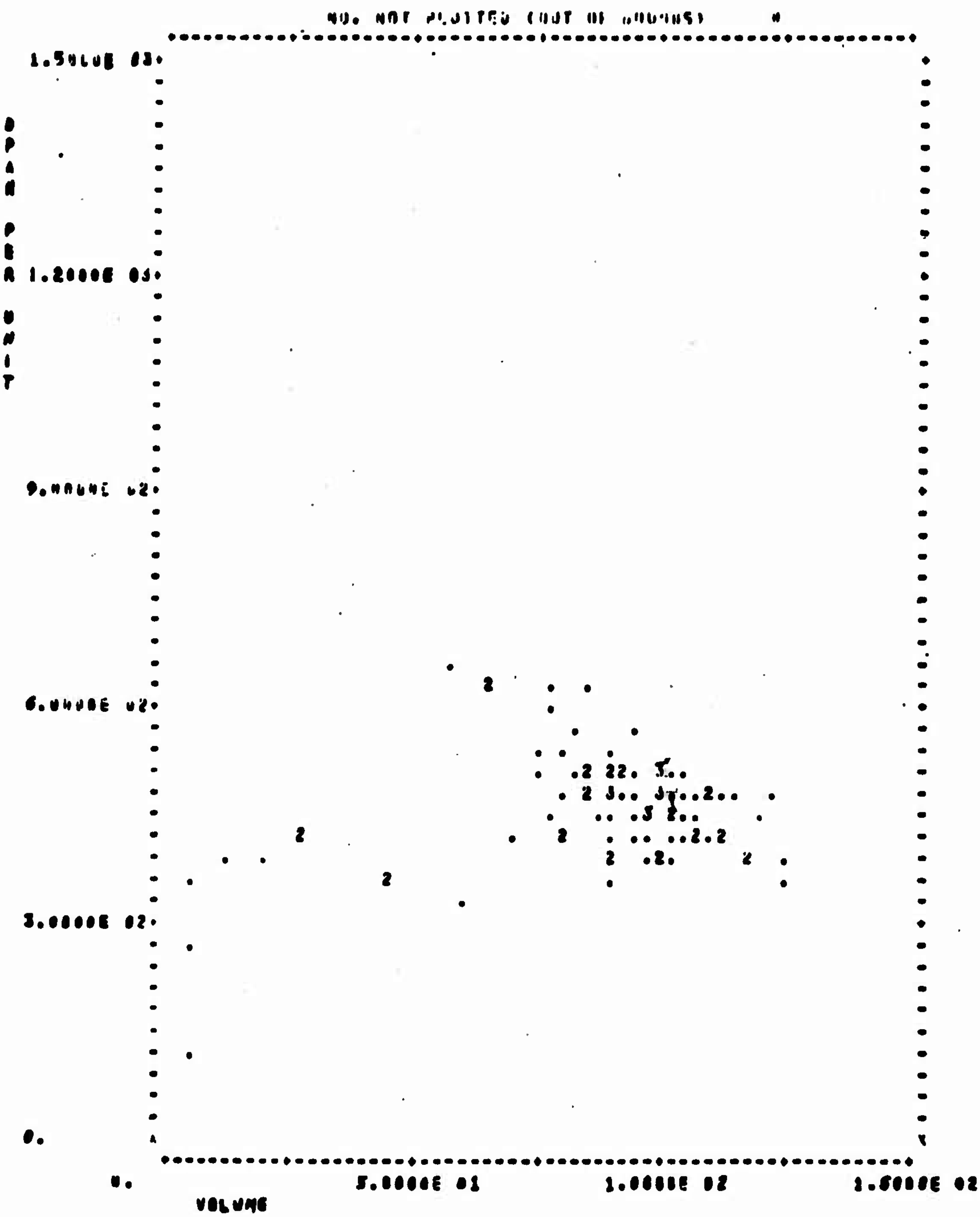
DPAN
LN12
DPAN PER UNIT
1.8932E 03
1.5145E 03
1.1359E 03
7.5727E 02
3.7863E 02
0.
0.0000E 00
9.7338E 01
1.0067E 02
2.0000E 02
VOLUME


WPAN NS10
NO. NOT PLOTTED (OUT OF BOUNDS) 3
1.5000E 03
1.2000E 03
9.0000E 02
6.0000E 02
3.0000E 02
0.
SPAN PER UNIT
0.
6.6667E 01
1.3333E 02
2.0000E 02
VOLUME

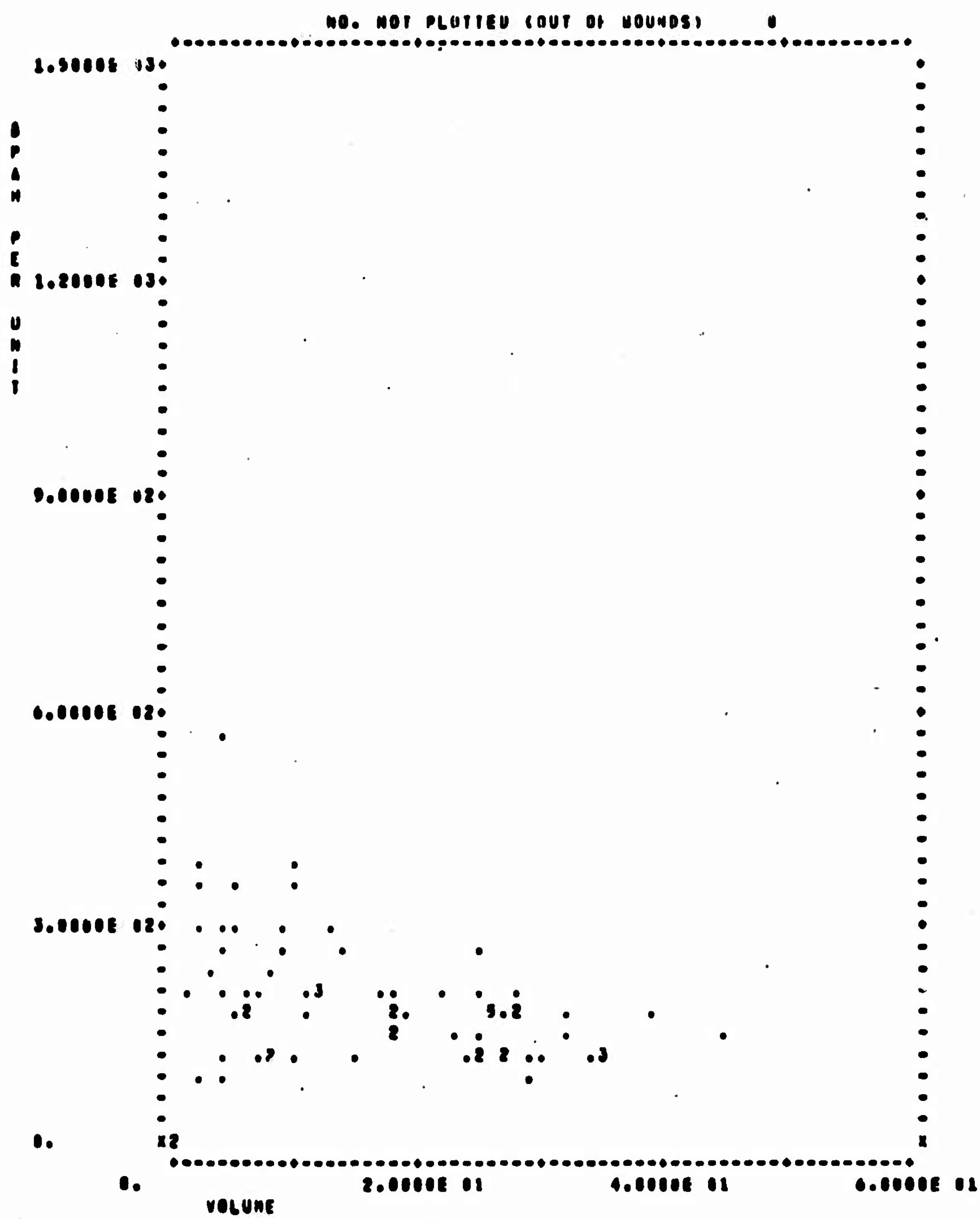
DPAN L6M25

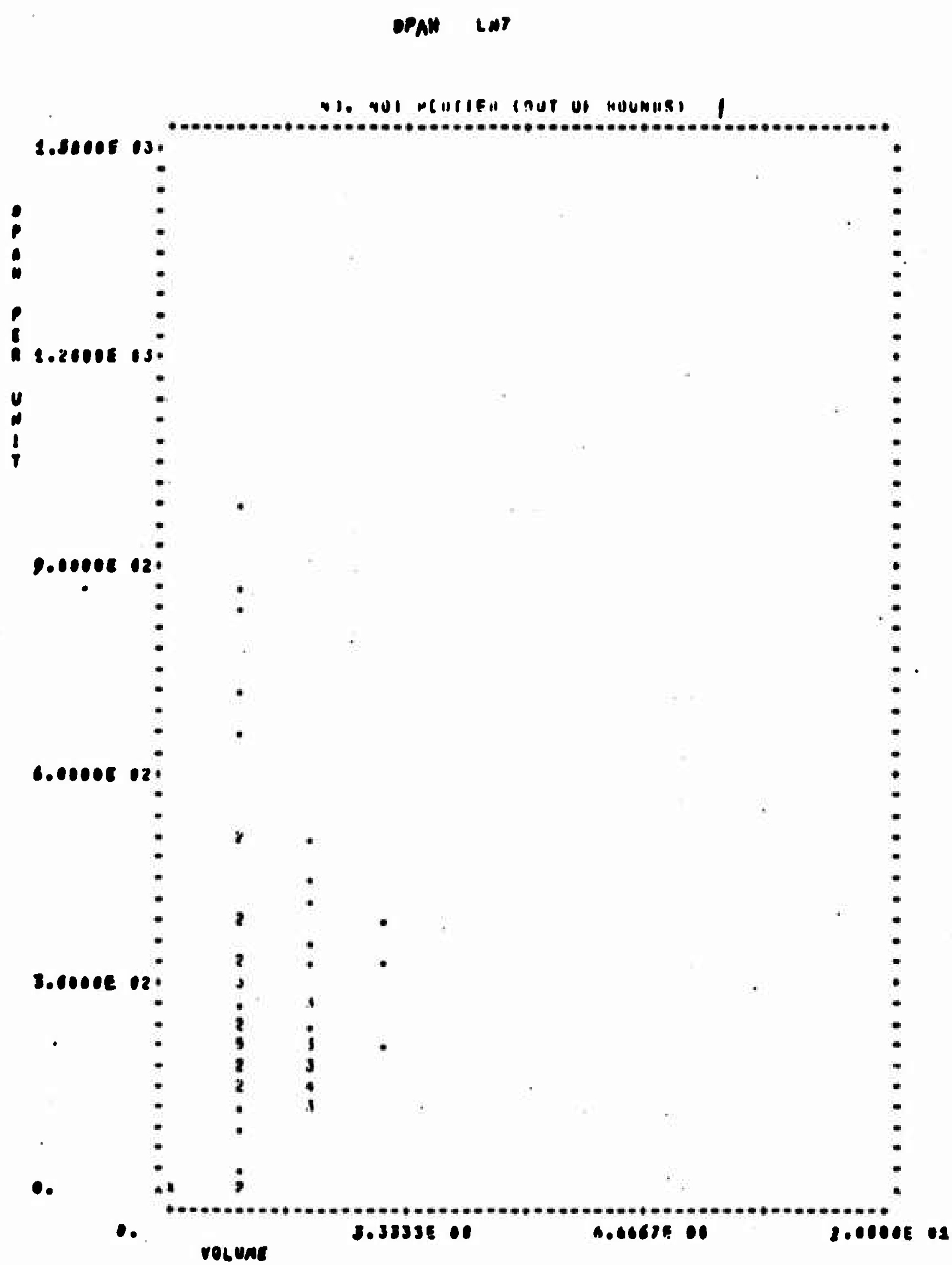

6.6150E 03
5.2920E 03
3.9690E 03
2.6460E 03
1.3230E 03
0.
DPAN PER UNIT
0.
8.6667E 00
1.7333E 01
2.6000E 01
VOLUME

SPAN WSL7

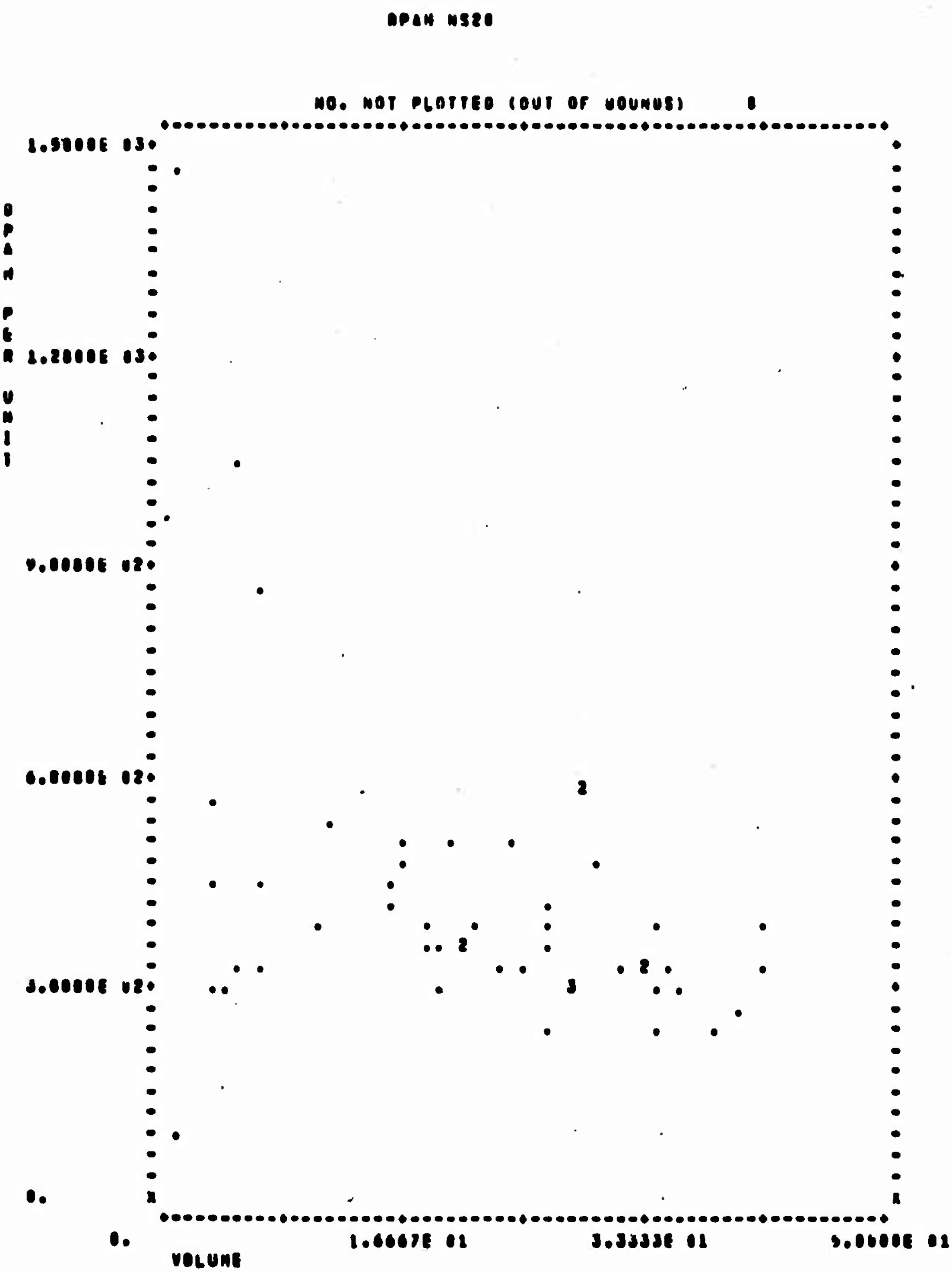

NO. NOT PLOTTED (OUT OF BOUNDS)
1.5000E 03
1.2000E 03
9.0000E 02
6.0000E 02
3.0000E 02
0.
SPAN PER UNIT
0.
5.0000E 01
1.0000E 02
1.5000E 02
VOLUME

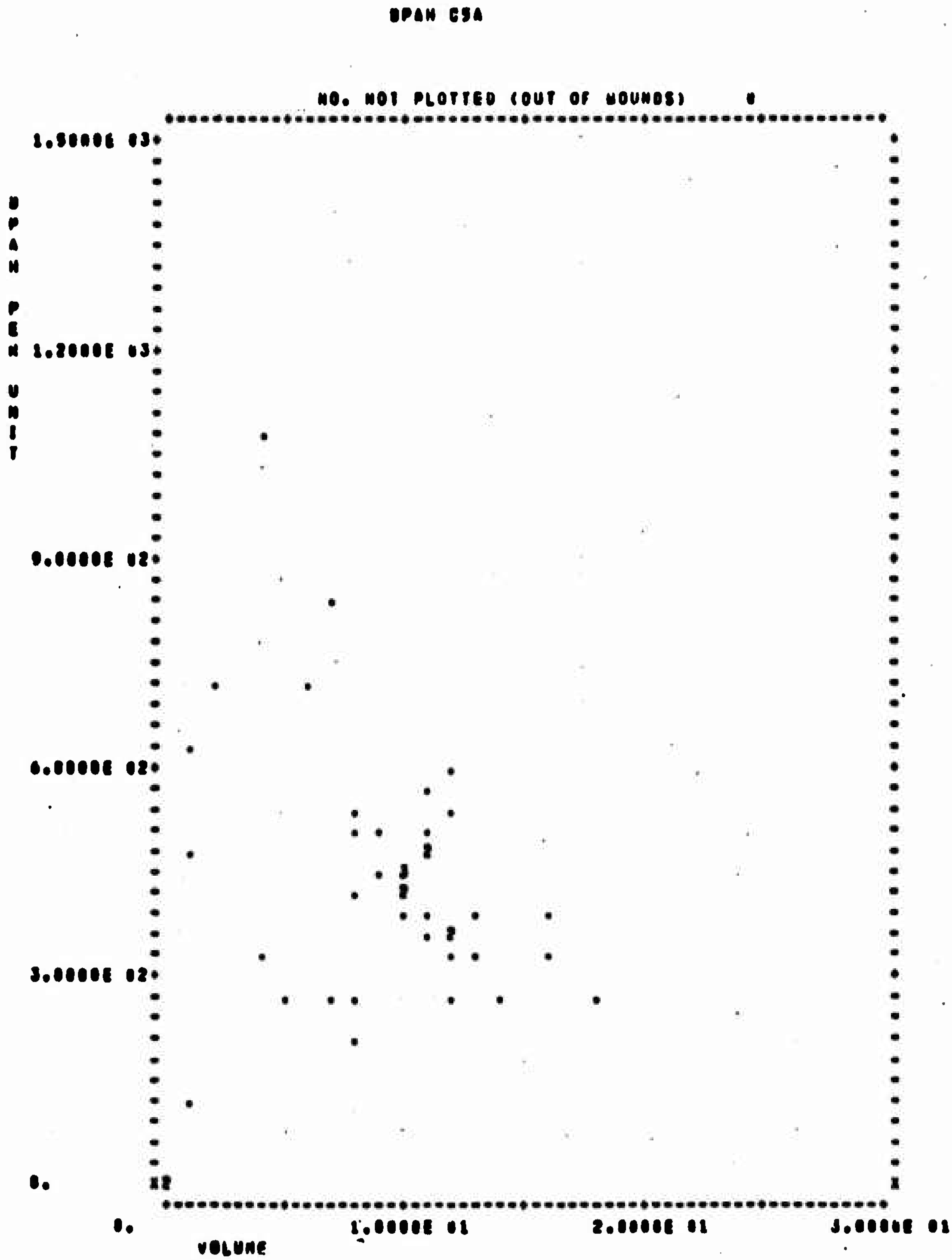
SPAN LN14


NO. NOT PLOTTED (OUT OF BOUNDS) 0
1.5000E 03
1.2000E 03
9.0000E 02
6.0000E 02
3.0000E 02
0.
SPAN PER UNIT
0.
2.0000E 01
4.0000E 01
6.0000E 01
VOLUME

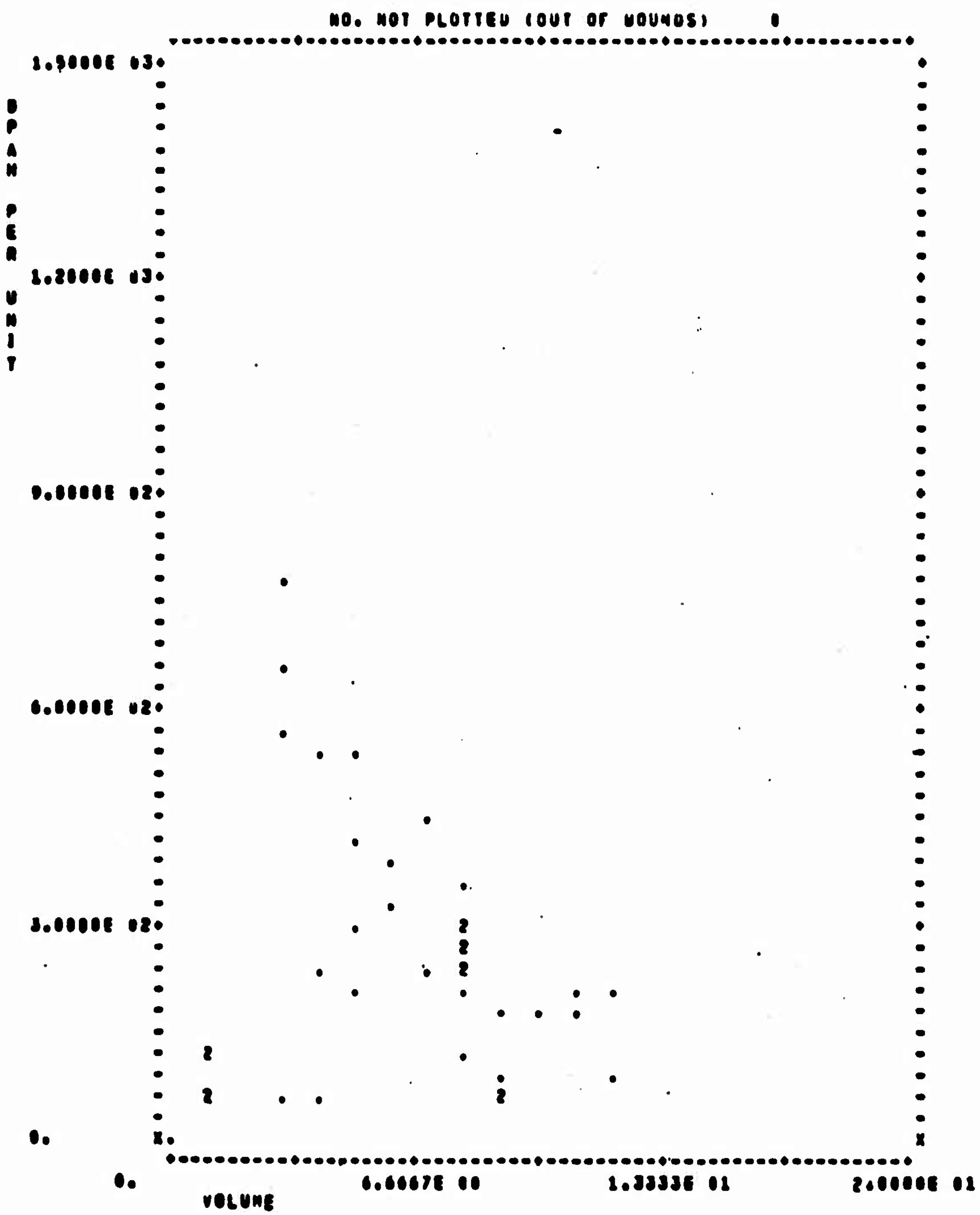


DPAN PER UNIT
1.5000E 03
1.2000E 03
9.0000E 02
6.0000E 02
3.0000E 02
0.
3.3333E 00
6.6667E 00
1.0000E 01
VOLUME


OPAN HS28
NO. NOT PLOTTED (OUT OF BOUNDS) 0
1.5000E 03
1.2000E 03
9.0000E 02
6.0000E 02
3.0000E 02
0.
0.
1.6667E 01
3.3333E 01
5.0000E 01
VOLUME
OPAN PER UNIT

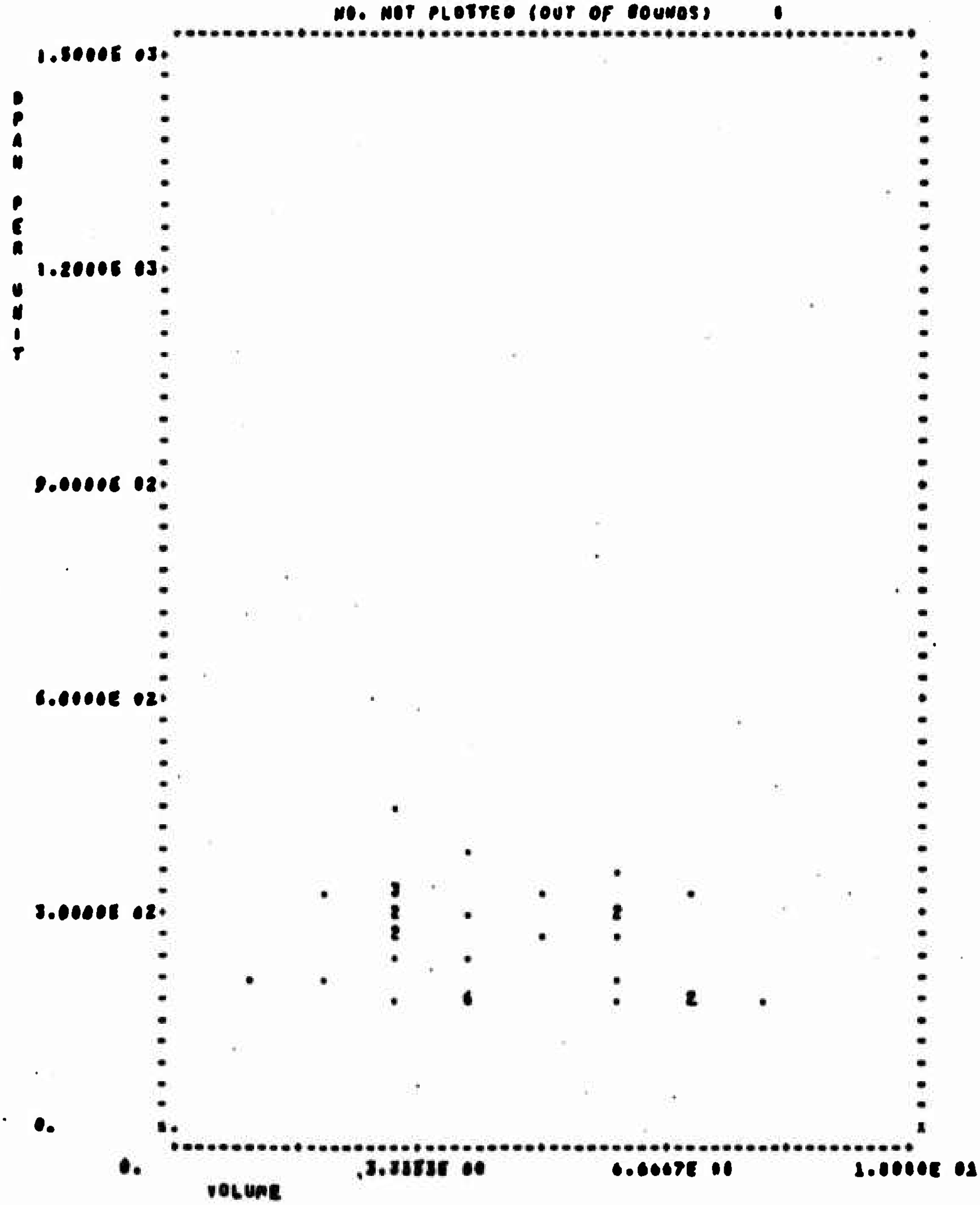

UPAN C5A
NO. NOT PLOTTED (OUT OF BOUNDS) 0
1.5000E 03
1.2000E 03
9.0000E 02
6.0000E 02
3.0000E 02
0.
UPAN PER UNIT
0.
1.0000E 01
2.0000E 01
3.0000E 01
VOLUME

DPAN M16

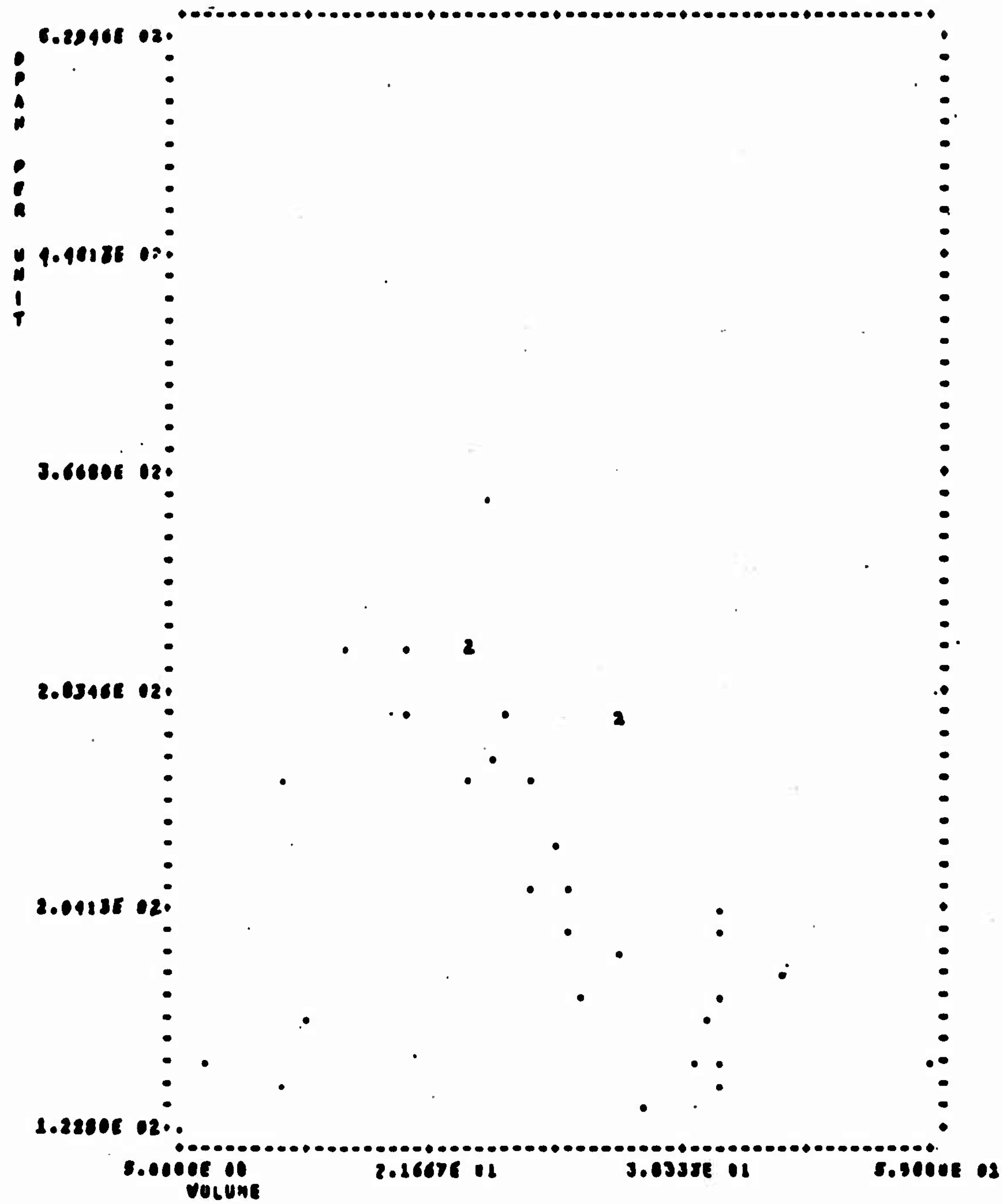

NO. NOT PLOTTED (OUT OF BOUNDS) 0
1.5000E 03
1.2000E 03
9.0000E 02
6.0000E 02
3.0000E 02
0.
DPAN PER UNIT
0.
6.6667E 00
1.3333E 01
2.0000E 01
VOLUME

DPAN KT71

NO. NOT PLOTTED (OUT OF BOUNDS) 0

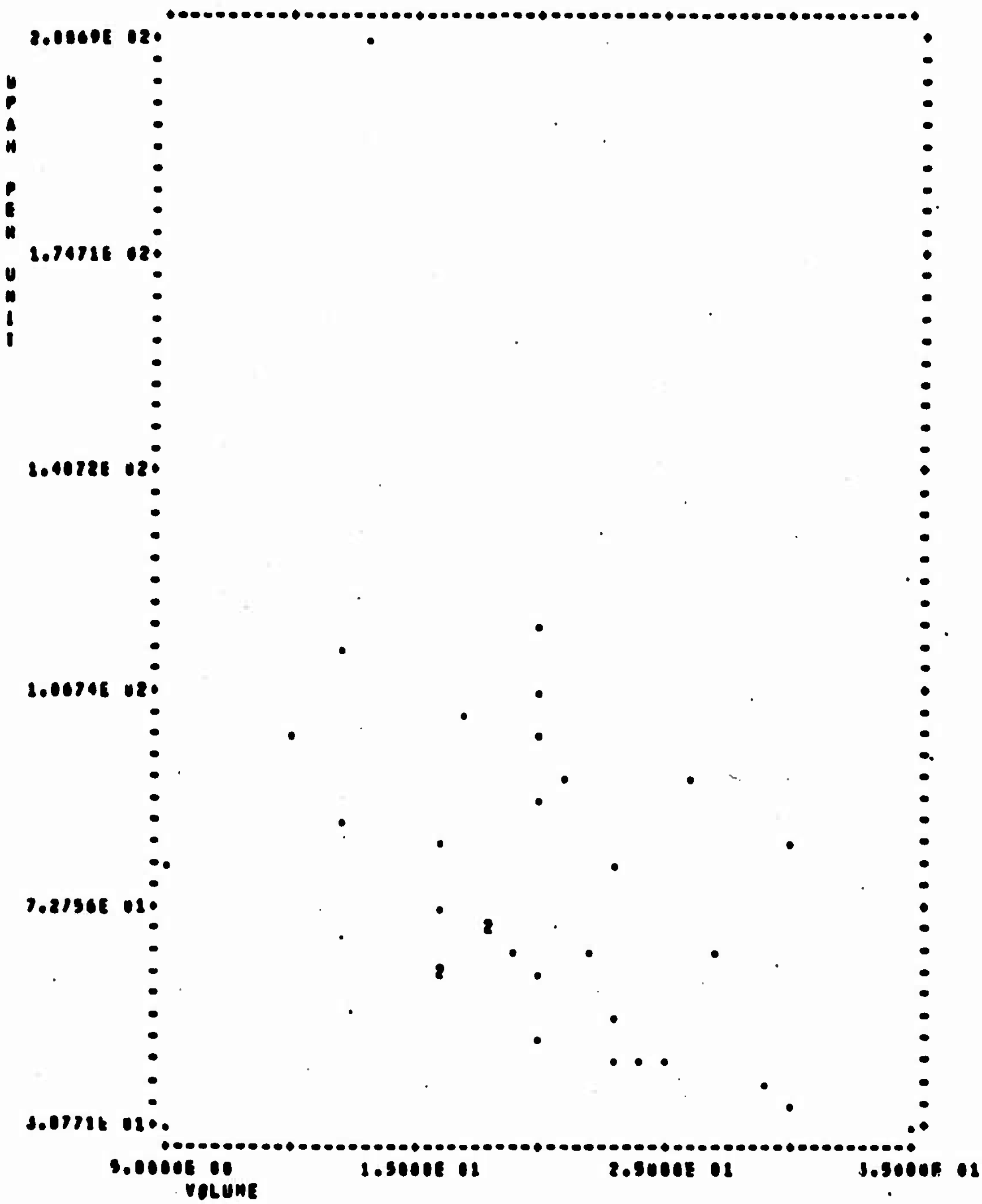


DPAN KT73

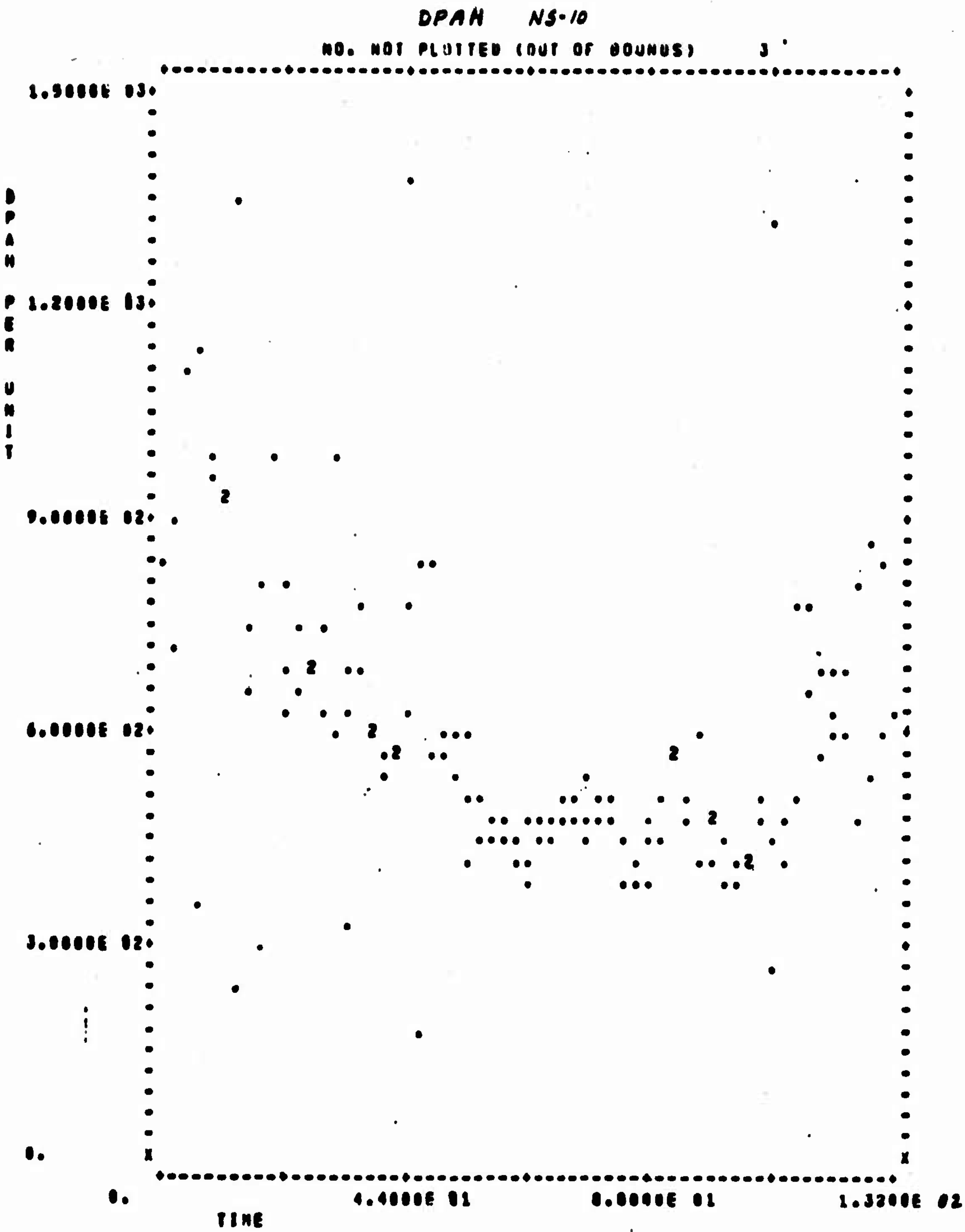


5.2946E 02
4.4813E 02
3.6680E 02
2.8346E 02
2.0413E 02
1.2280E 02
DPAN PER UNIT
5.0000E 00
2.1667E 01
3.8333E 01
5.5000E 01
VOLUME

UPAH N16BY



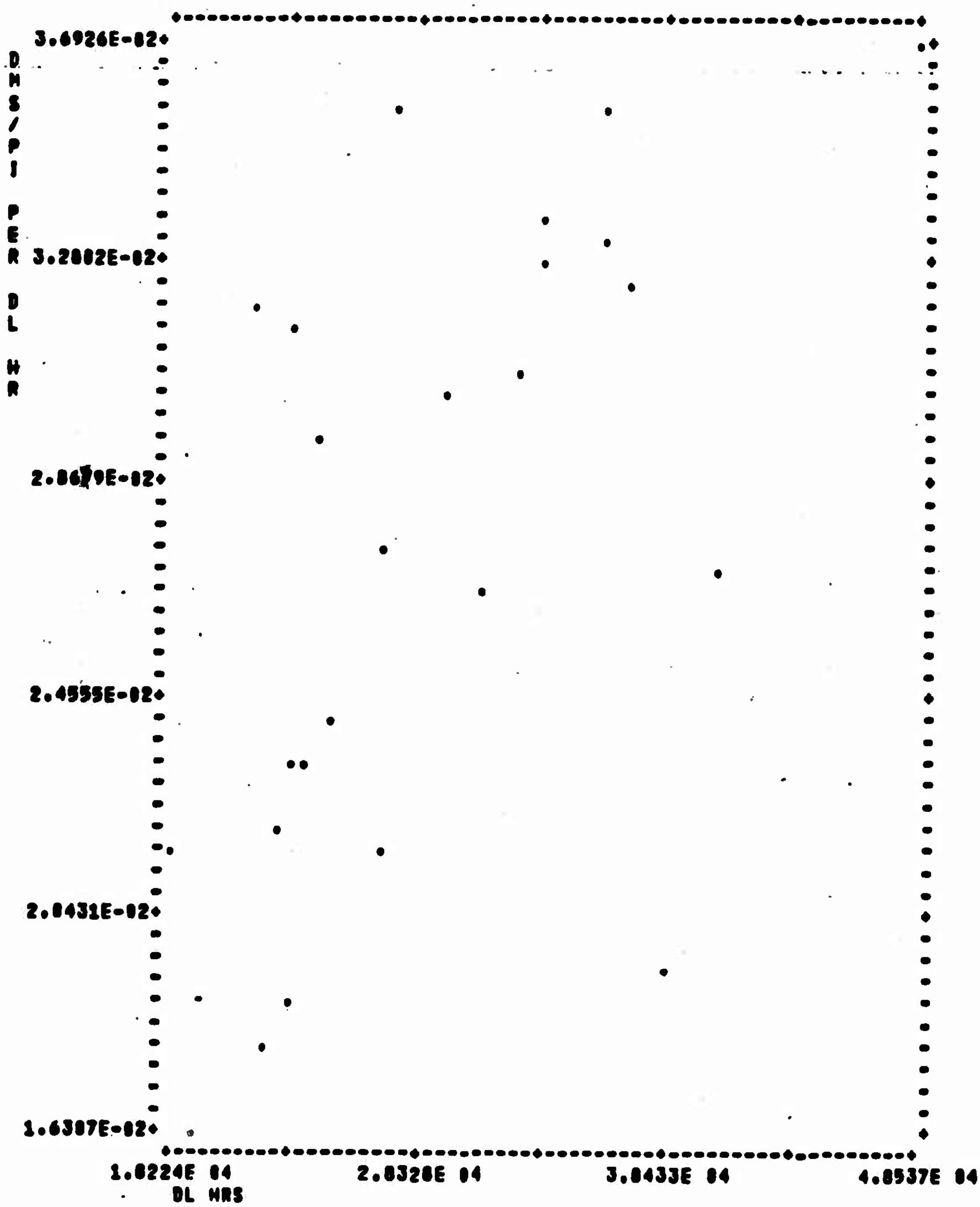
2.0869E 02
1.7471E 02
1.4072E 02
1.0674E 02
7.2756E 01
3.8771E 01
UPAH PER UNIT
5.0000E 00
1.5000E 01
2.5000E 01
3.5000E 01
VOLUME


DPAH NS-10
NO. NOT PLOTTED (OUT OF BOUNDS) 3
1.5000E 03
1.2000E 03
9.0000E 02
6.0000E 02
3.0000E 02
0.
DPAH PER UNIT
0.
4.4000E 01
8.8000E 01
1.3200E 02
TIME

Appendix C

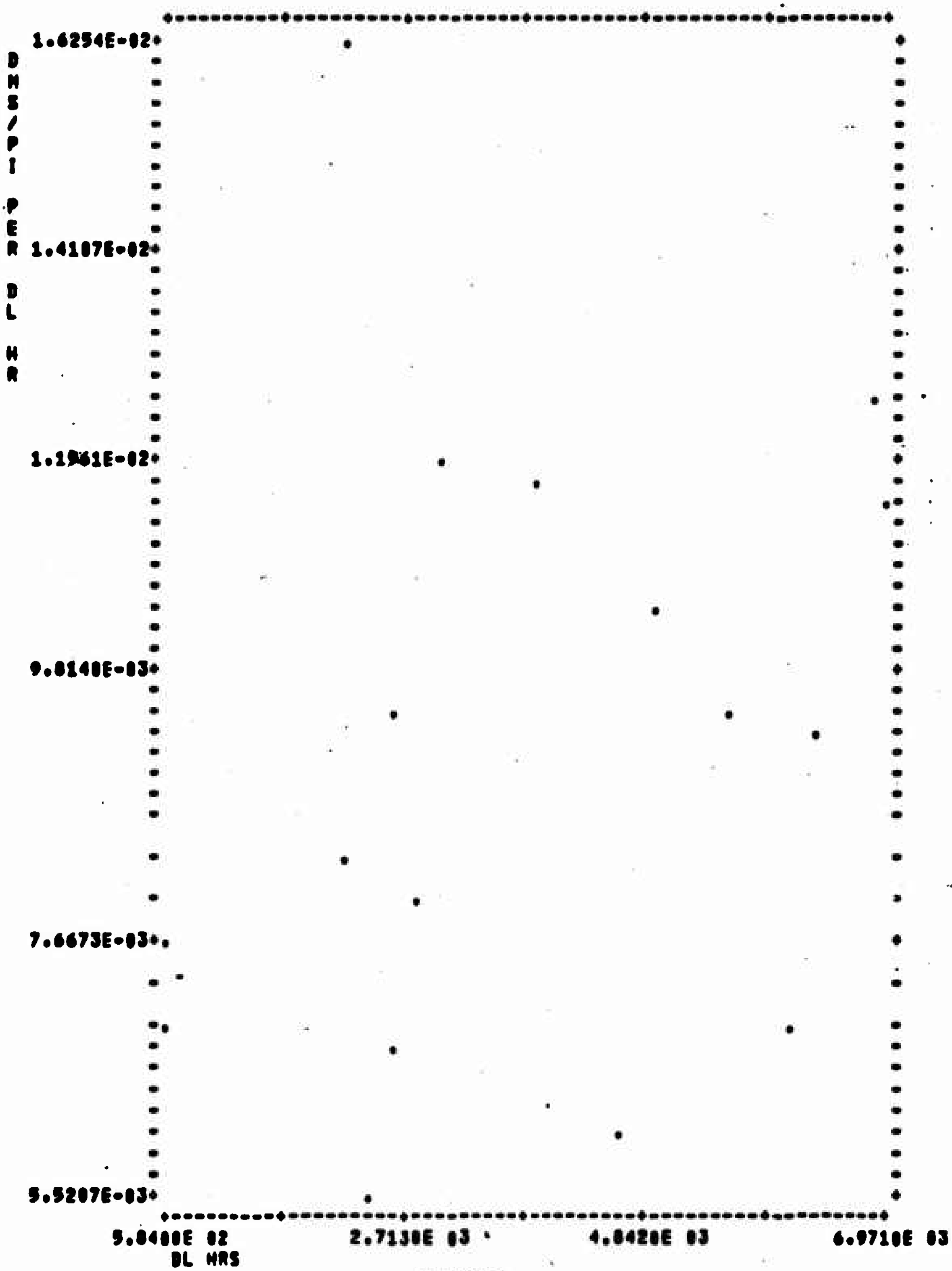
Graphs of Direct Material vs Direct Labor Hours

DIR MAT LN-12



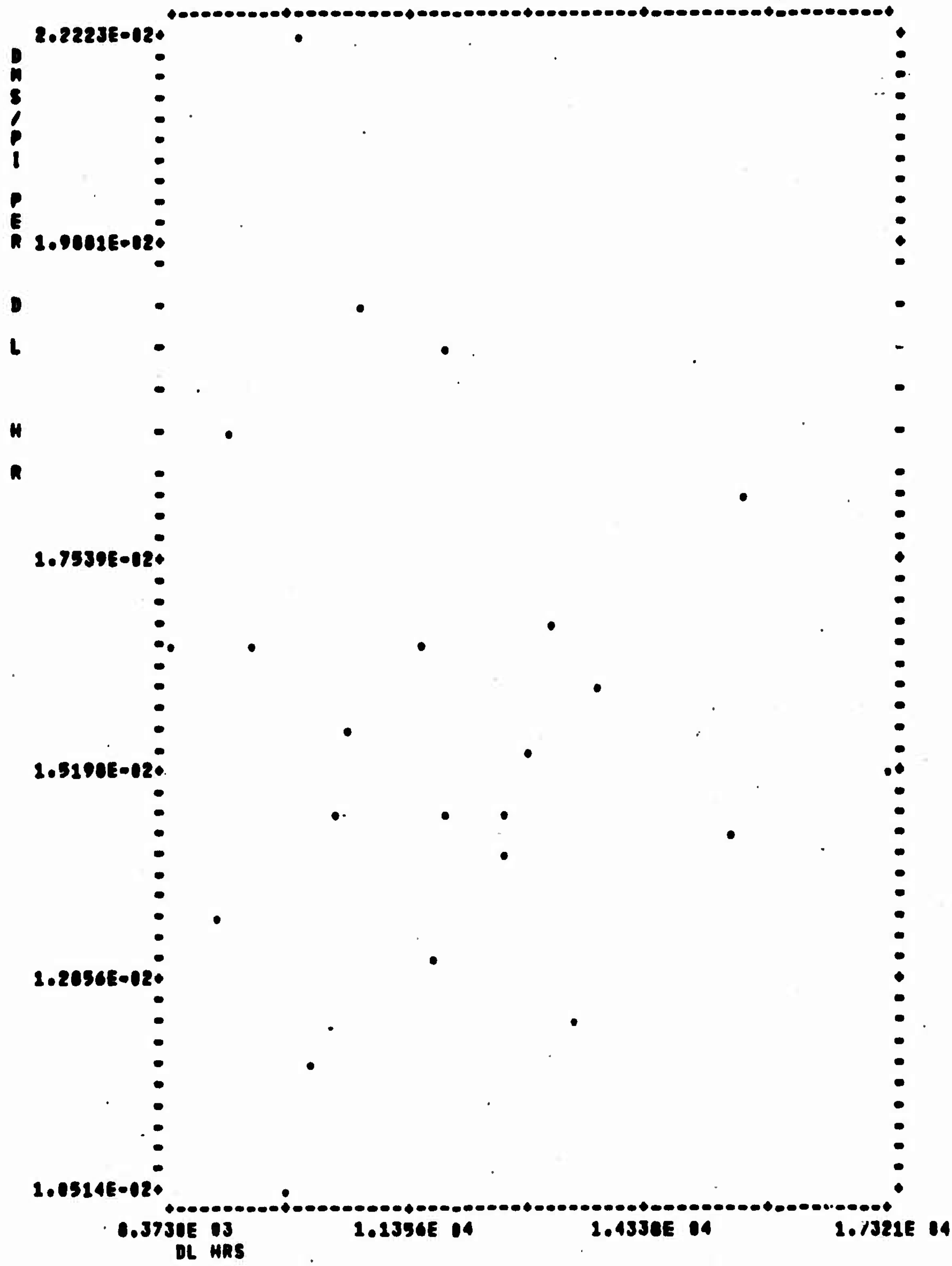
3.6926E-02
3.2802E-02
2.8679E-02
2.4555E-02
2.0431E-02
1.6307E-02
DMS/PI PER DL HR
1.0224E 04
2.0328E 04
3.0433E 04
4.0537E 04
DL HRS

DIR MAT NS-10

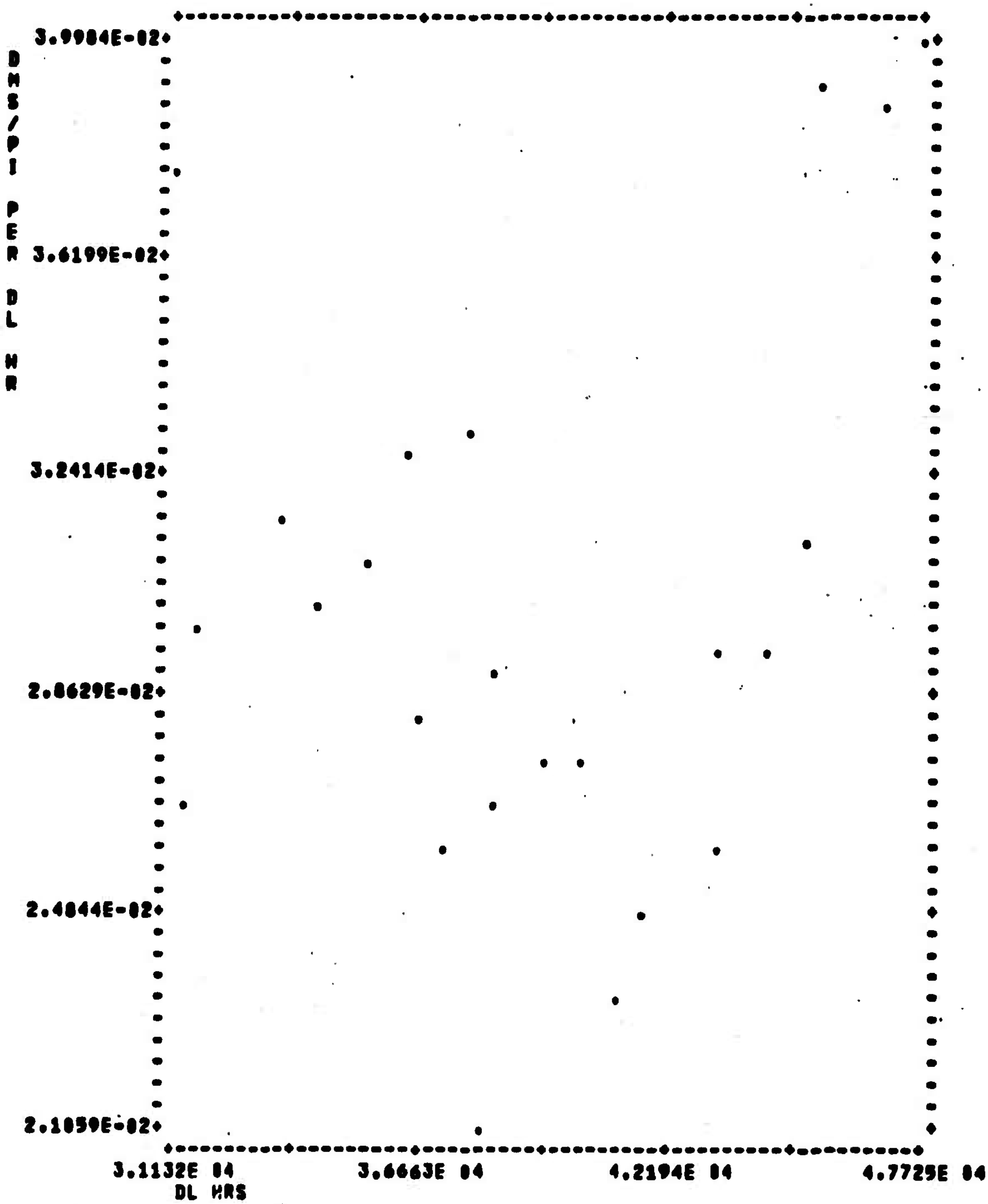


1.6254E-02
1.4107E-02
1.1961E-02
9.8140E-03
7.6673E-03
5.5207E-03
DMS/PI PER DL HR
5.8400E 02
2.7130E 03
4.8420E 03
6.9710E 03
DL HRS

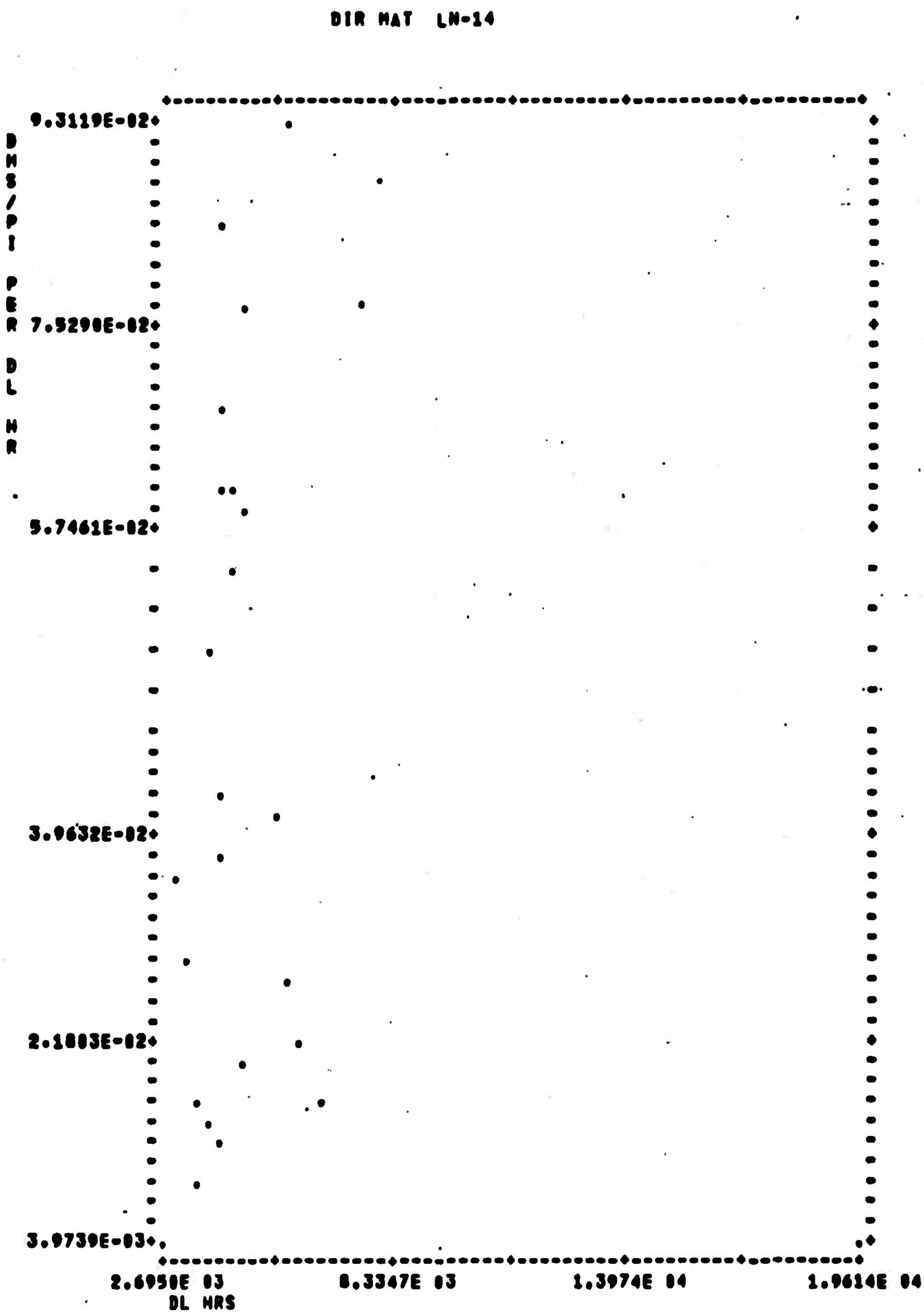
DIR MAT LGM-25



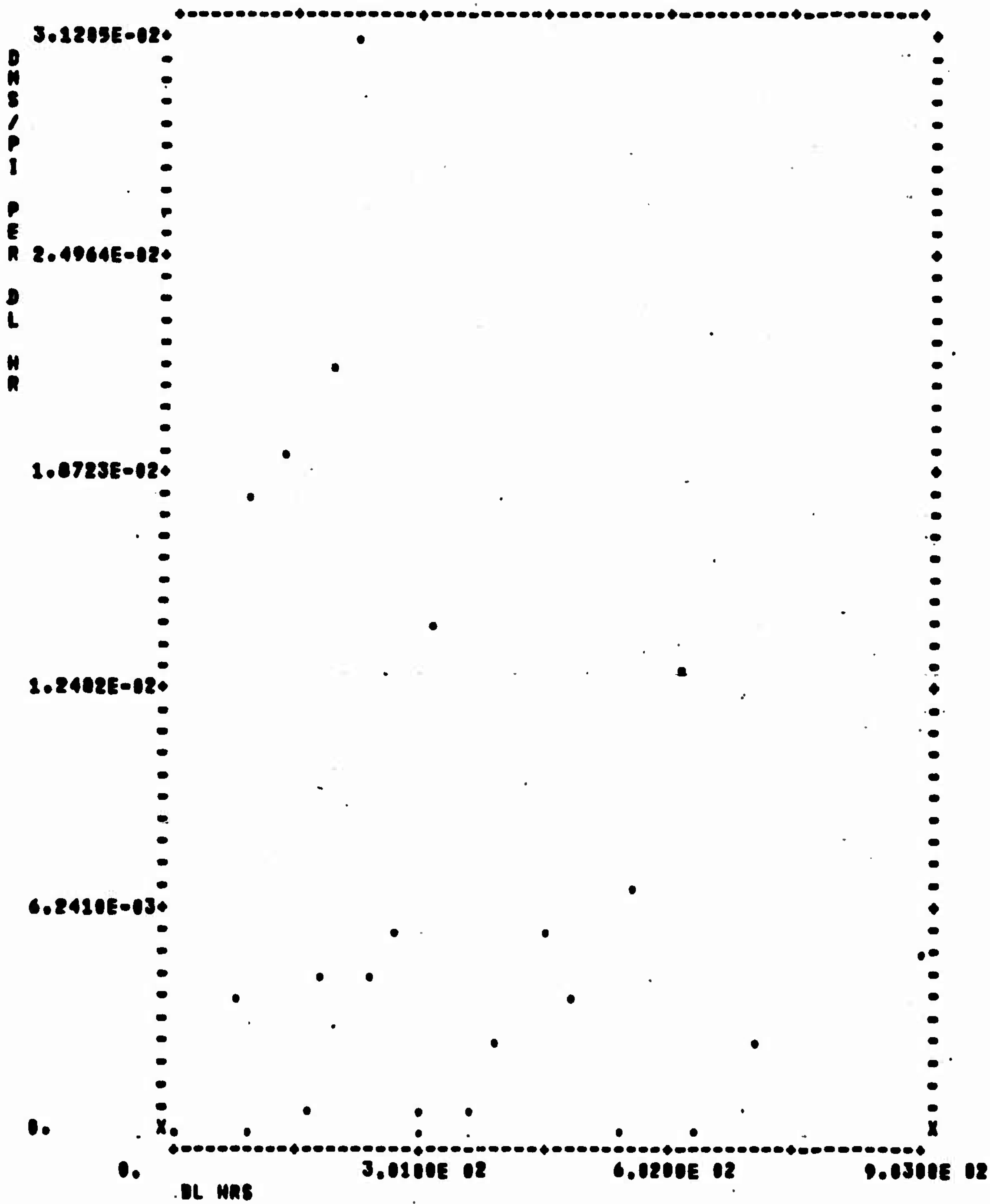
DIR MAT NS-17



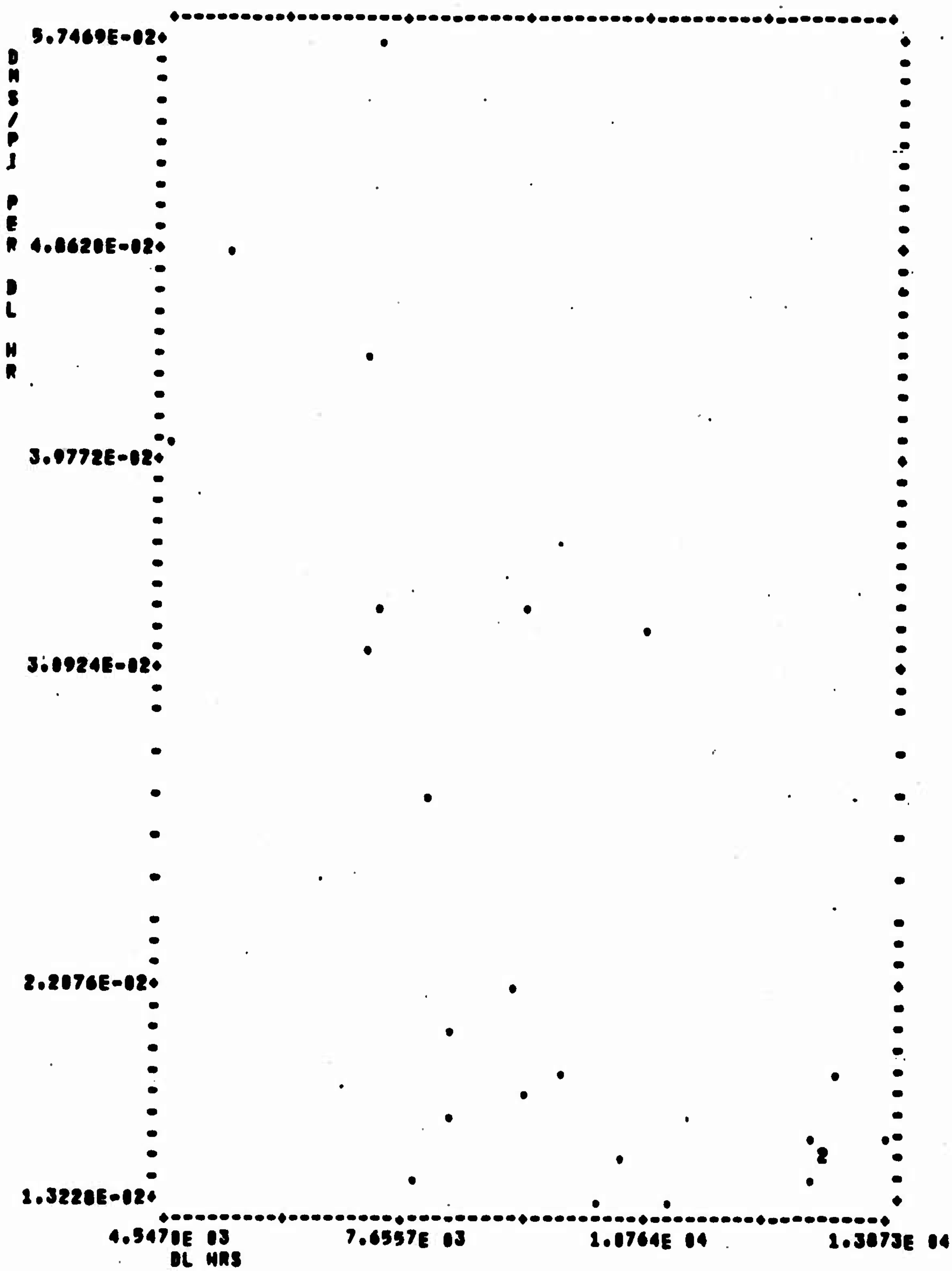
DMS/PI PER DL HR
3.9984E-02
3.6199E-02
3.2414E-02
2.8629E-02
2.4844E-02
2.1059E-02
3.1132E 04
3.6663E 04
4.2194E 04
4.7725E 04
DL HRS


DIR MAT LN-14
9.3119E-02
7.5290E-02
5.7461E-02
3.9632E-02
2.1803E-02
3.9739E-03
DMS/PI PER DL HR
2.6950E 03
8.3347E 03
1.3974E 04
1.9614E 04
DL HRS

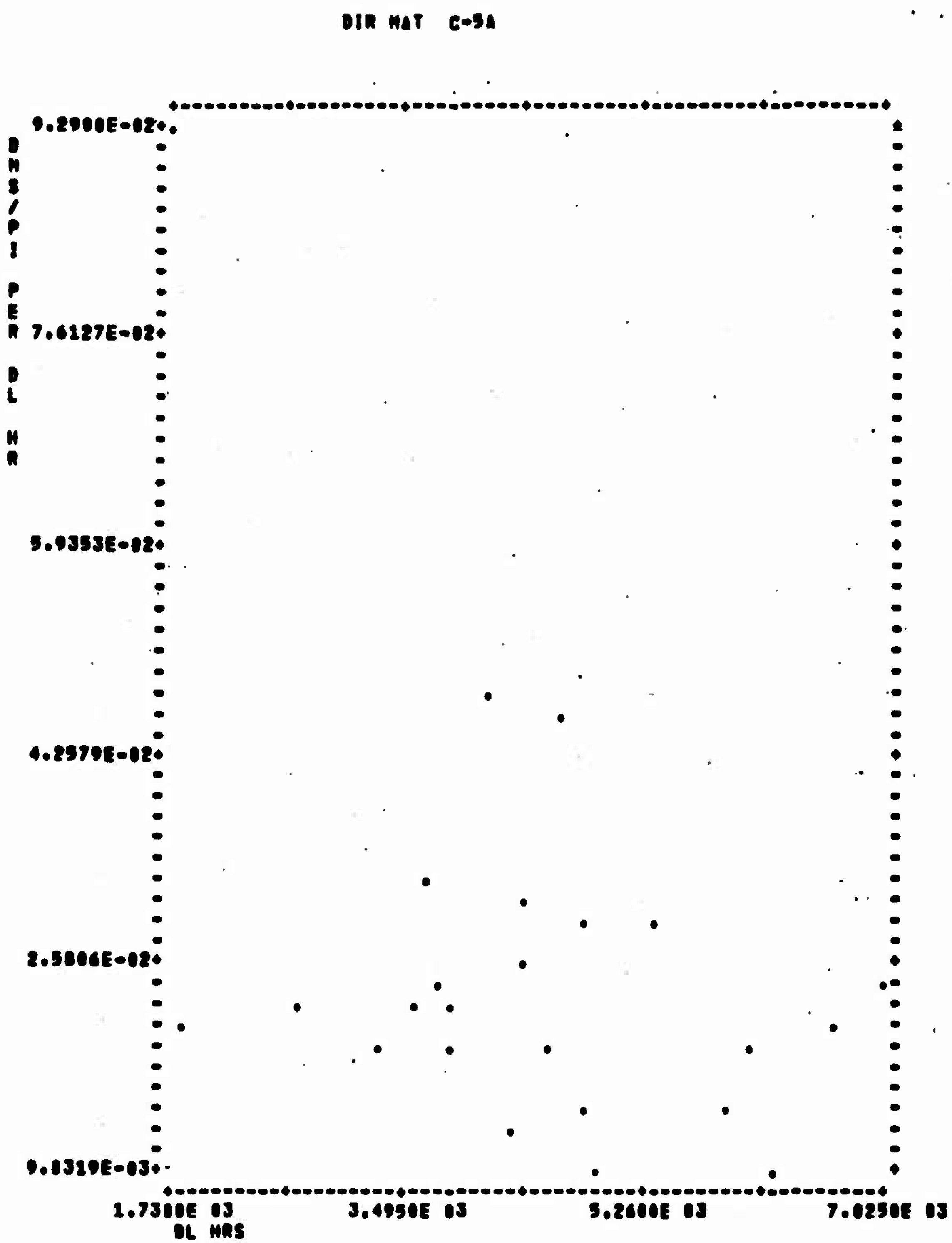
DIR MAT LN-7


3.1205E-02
2.4964E-02
1.8723E-02
1.2482E-02
6.2410E-03
0.
DHS/PI PER DL HR
0.
3.0100E 02
6.0200E 02
9.0300E 02
DL HRS

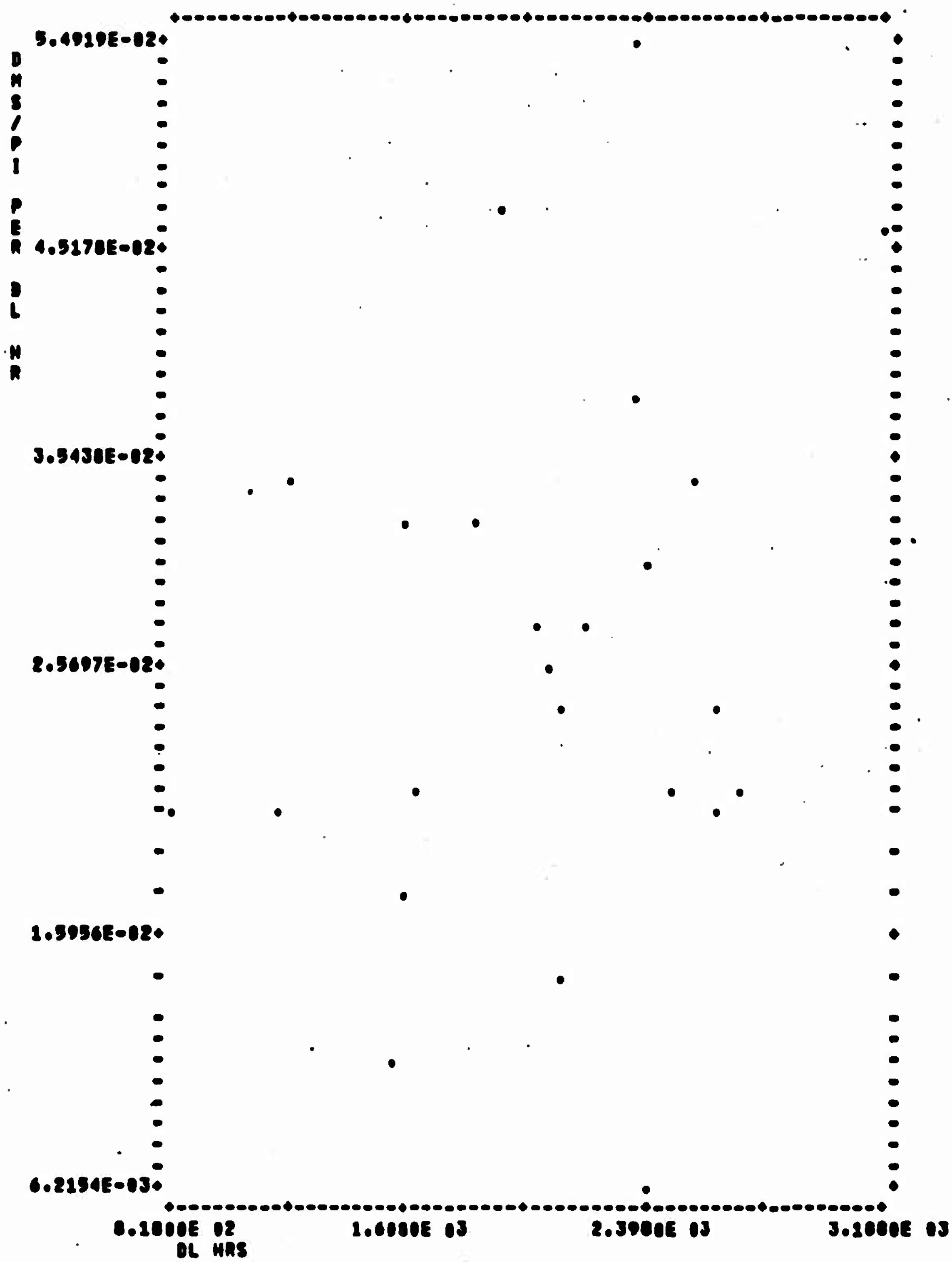
DIR MAT NS-20



5.7469E-02
4.8620E-02
3.9772E-02
3.0924E-02
2.2076E-02
1.3228E-02
DMS/PI PER DL HR
4.5470E 03
7.6557E 03
1.0764E 04
1.3873E 04
DL HRS

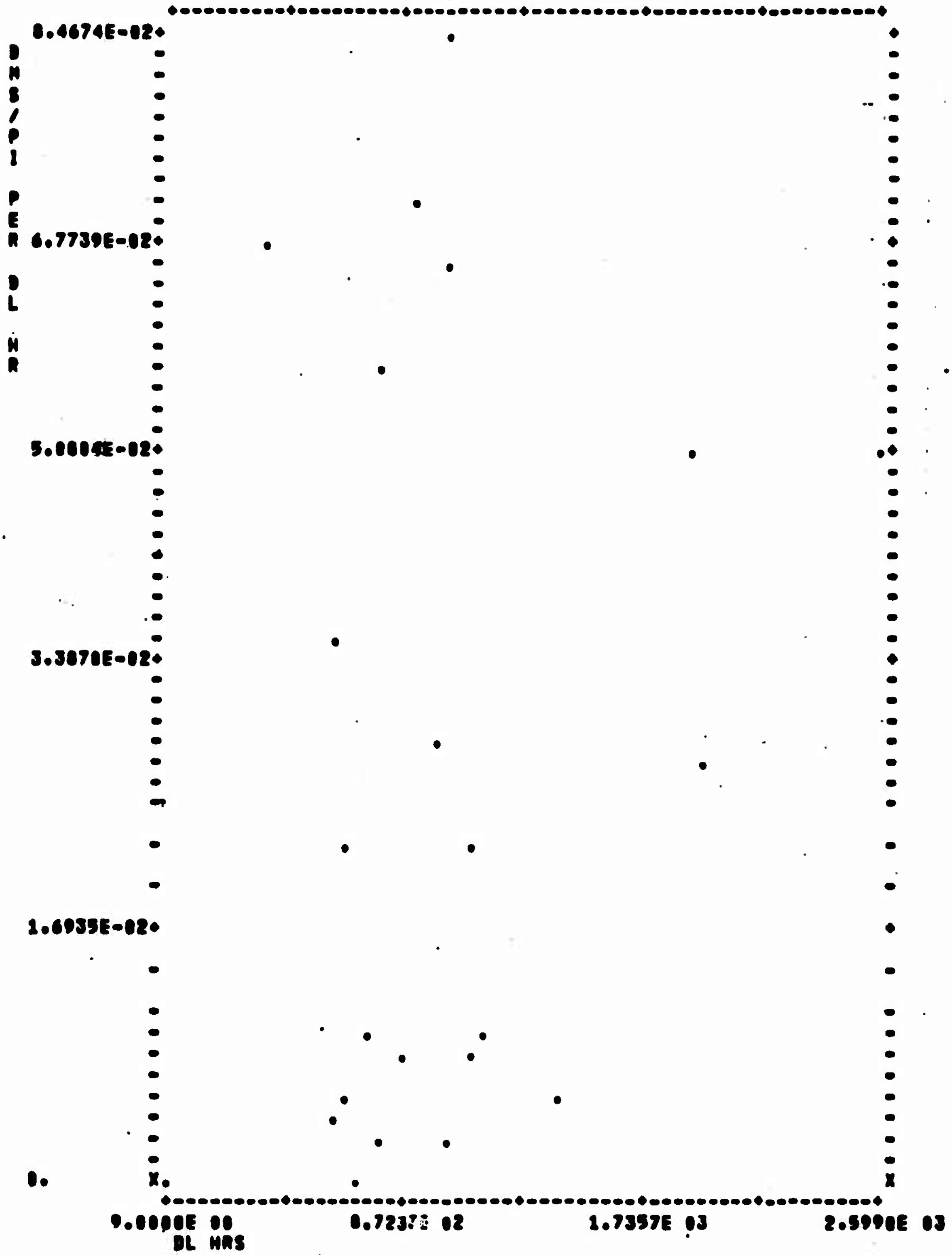

DIR MAT C-5A
9.2900E-02
7.6127E-02
5.9353E-02
4.2579E-02
2.5806E-02
9.0319E-03
DMS/PI PER DL HR
1.7300E 03
3.4950E 03
5.2600E 03
7.0250E 03
DL HRS

DIR MAT N-16

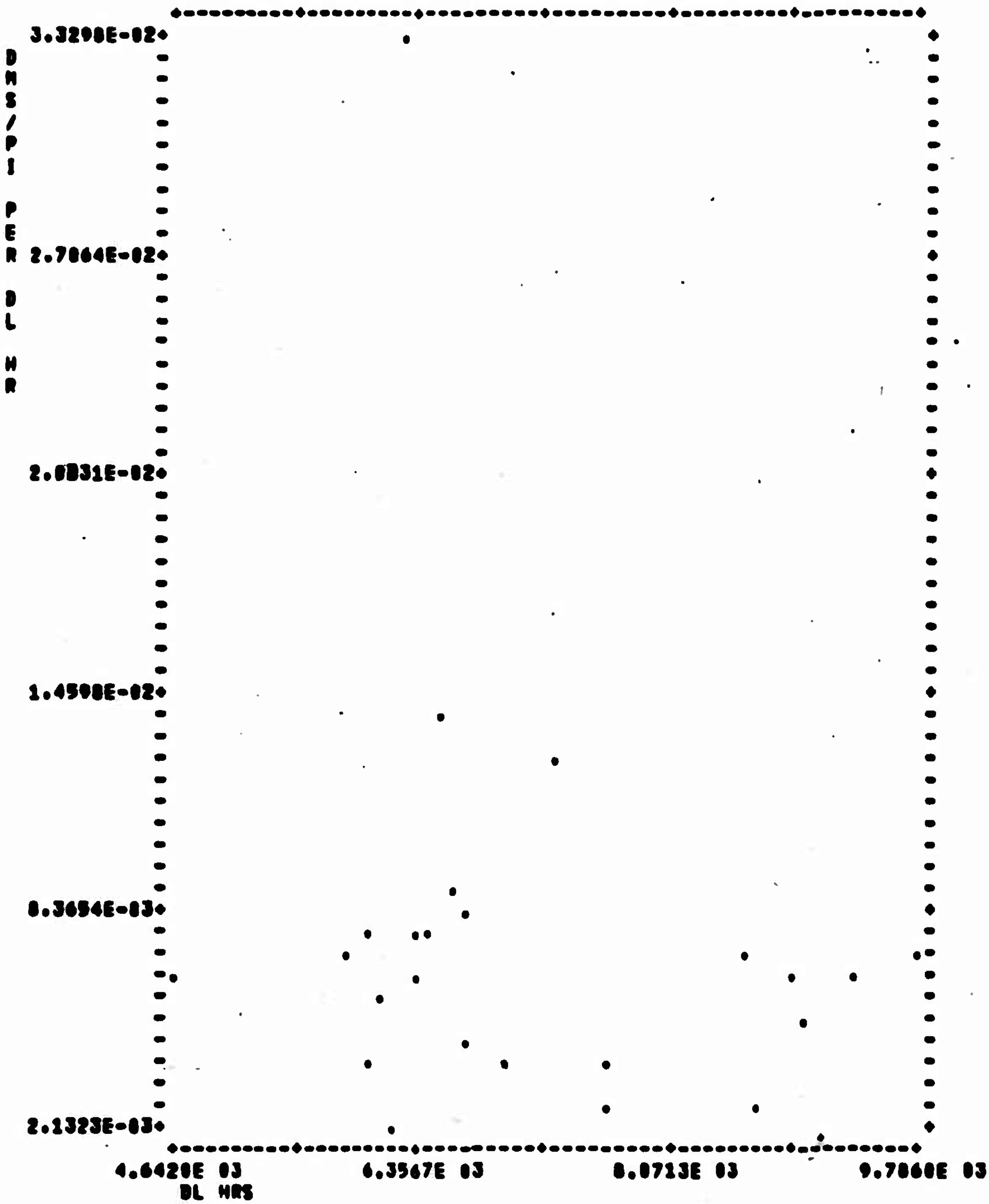


DMS/PI PER BL HR
5.4919E-02
4.5178E-02
3.5438E-02
2.5697E-02
1.5956E-02
6.2154E-03
0.1000E 02
1.6000E 03
2.3900E 03
3.1800E 03
BL HRS

DIR MAT KT-71

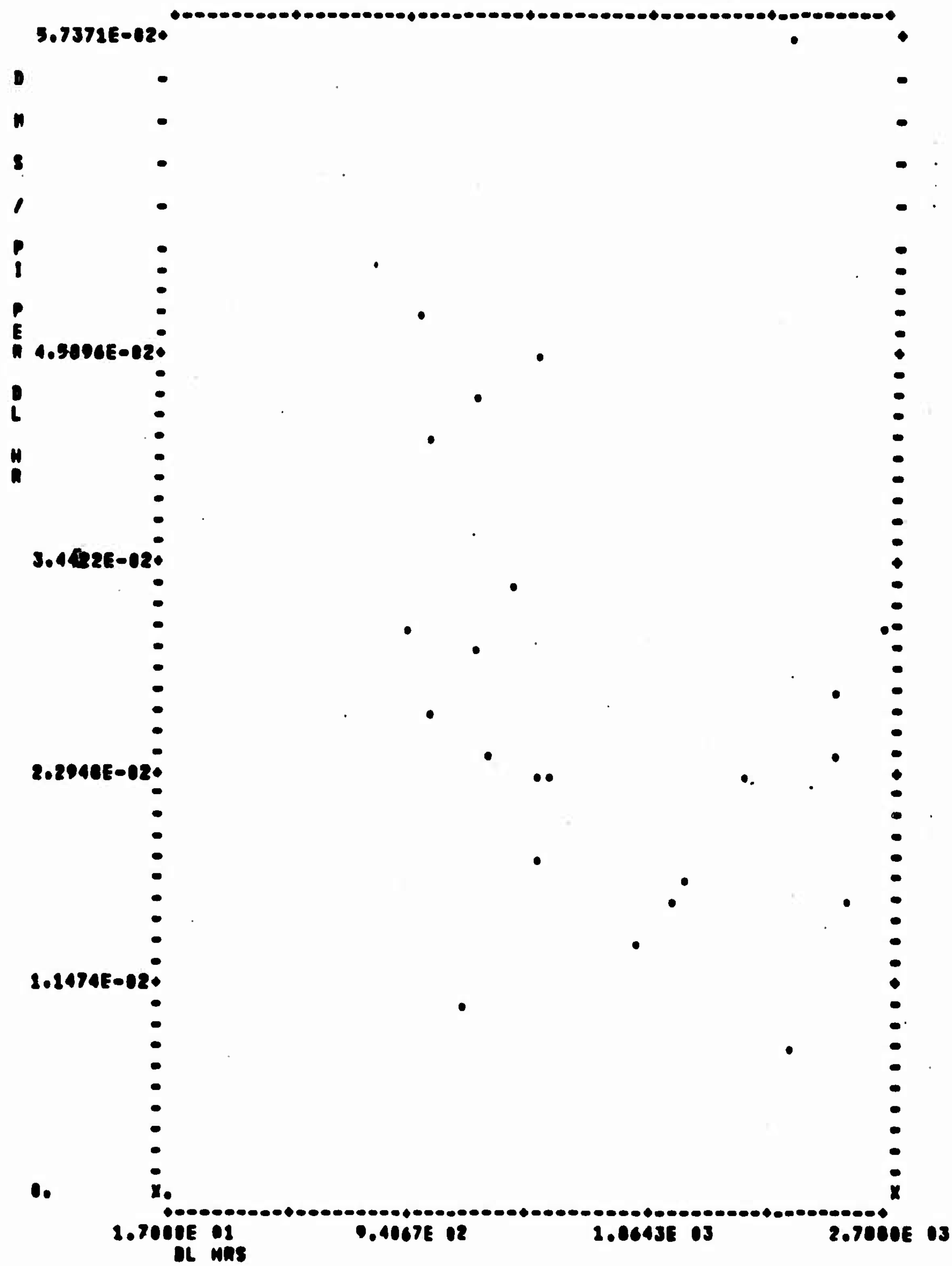

8.4674E-02
6.7739E-02
5.0804E-02
3.3870E-02
1.6935E-02
0.
DNS/PI PER DL HR
0.0000E 00
8.7237E 02
1.7357E 03
2.5990E 03
DL HRS

BIR MAT KT-73



DNS/PI PER DL HR
3.3298E-02
2.7064E-02
2.0831E-02
1.4598E-02
8.3654E-03
2.1323E-03
4.6420E 03
6.3567E 03
8.0713E 03
9.7860E 03
DL HRS

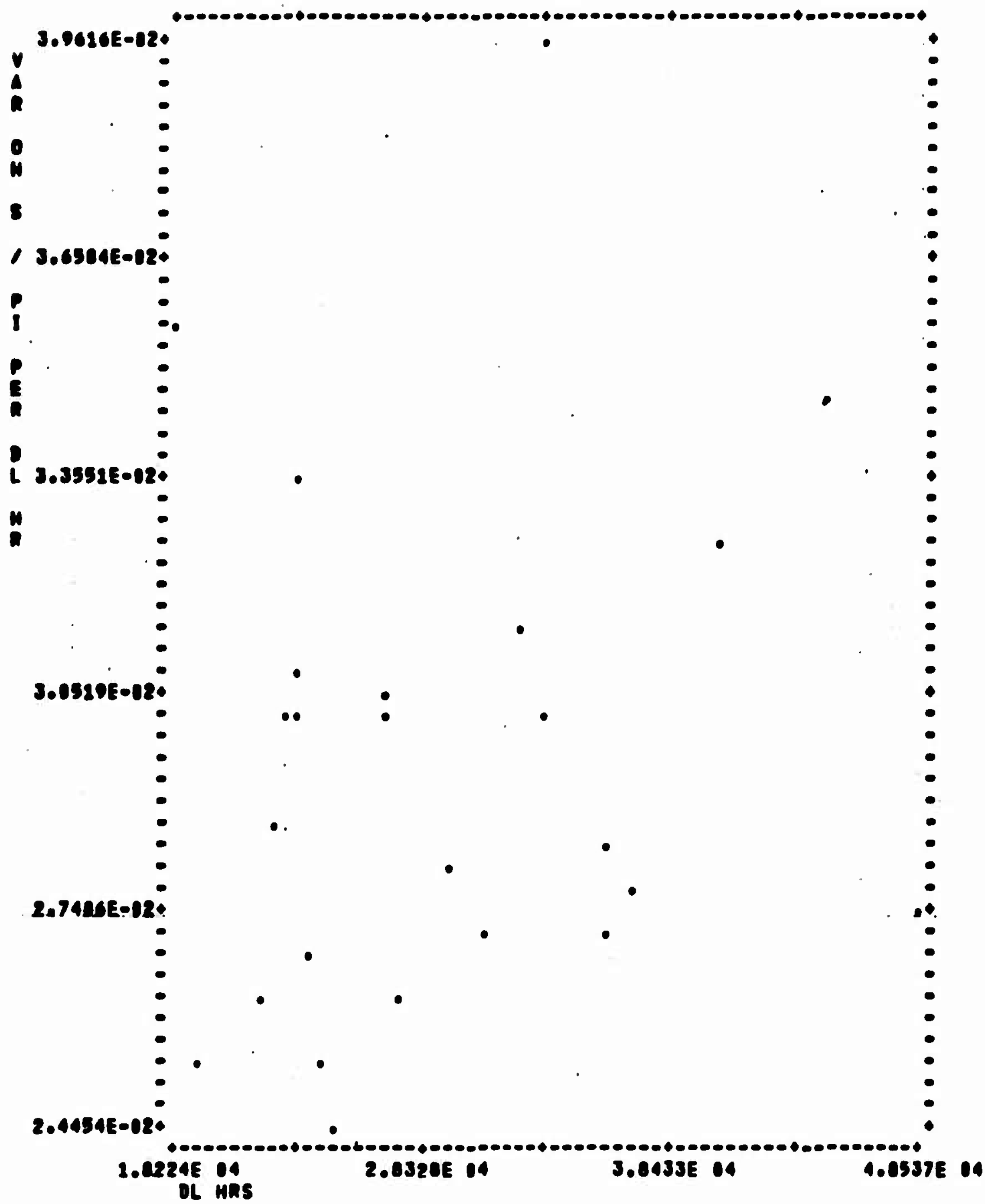
DIR MAT N-16BY



Appendix D

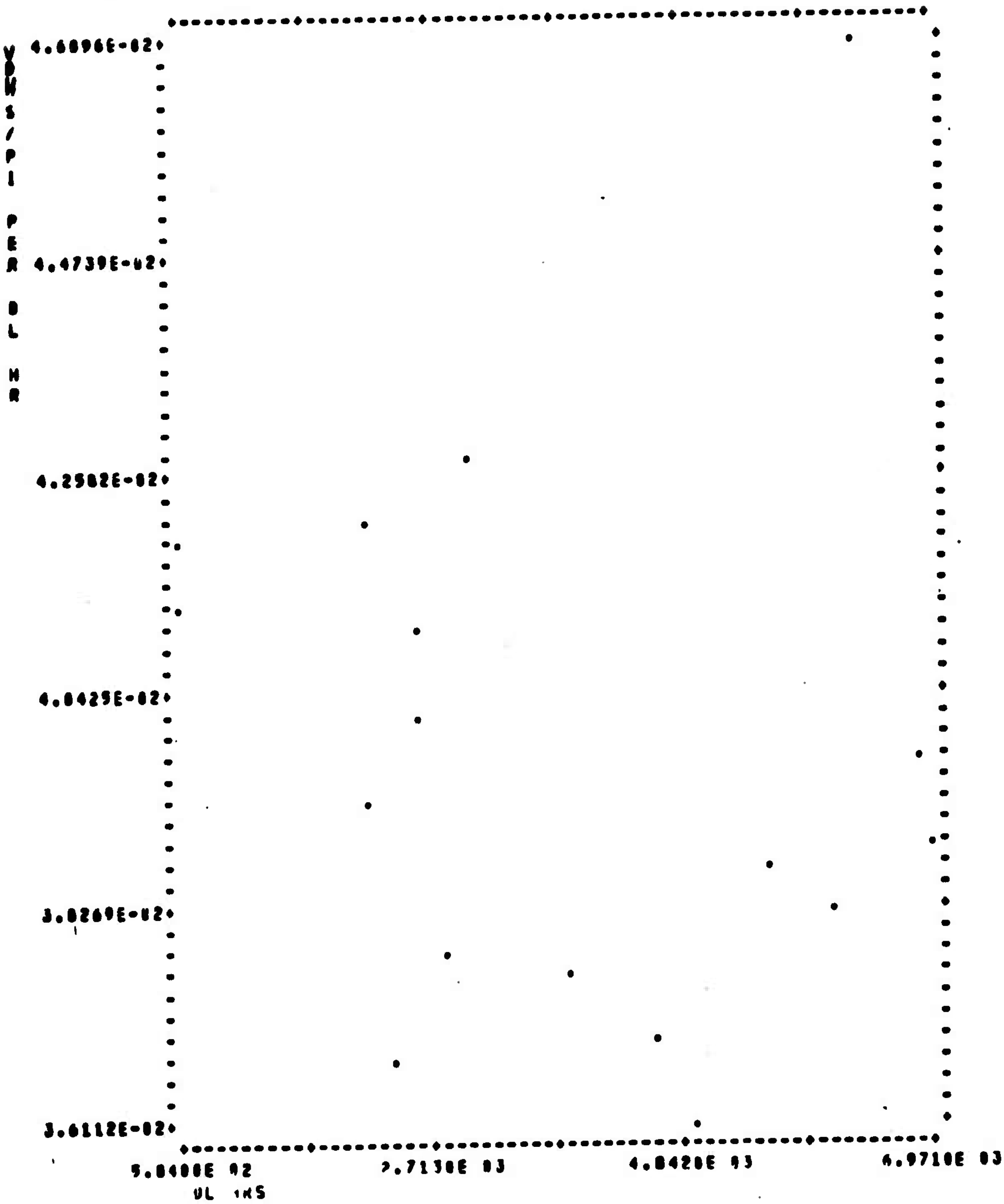
Graphs of Variable Overhead vs Direct Labor Hours

VAR OH LN-12

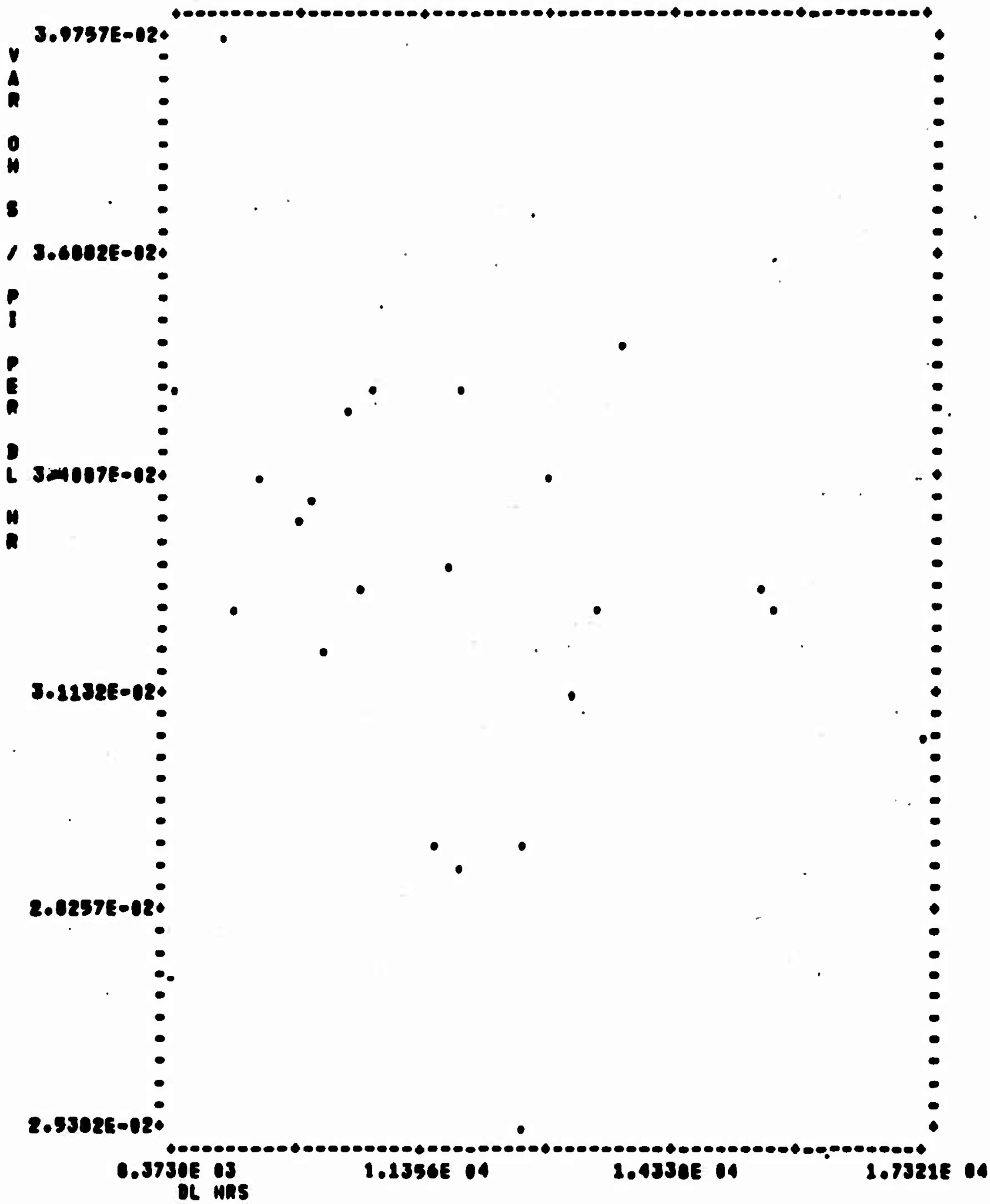


3.9616E-02
3.6584E-02
3.3551E-02
3.0519E-02
2.7486E-02
2.4454E-02
VAR OHNS / PI PER DL HR
1.8224E 04
2.8328E 04
3.8433E 04
4.8537E 04
DL HRS

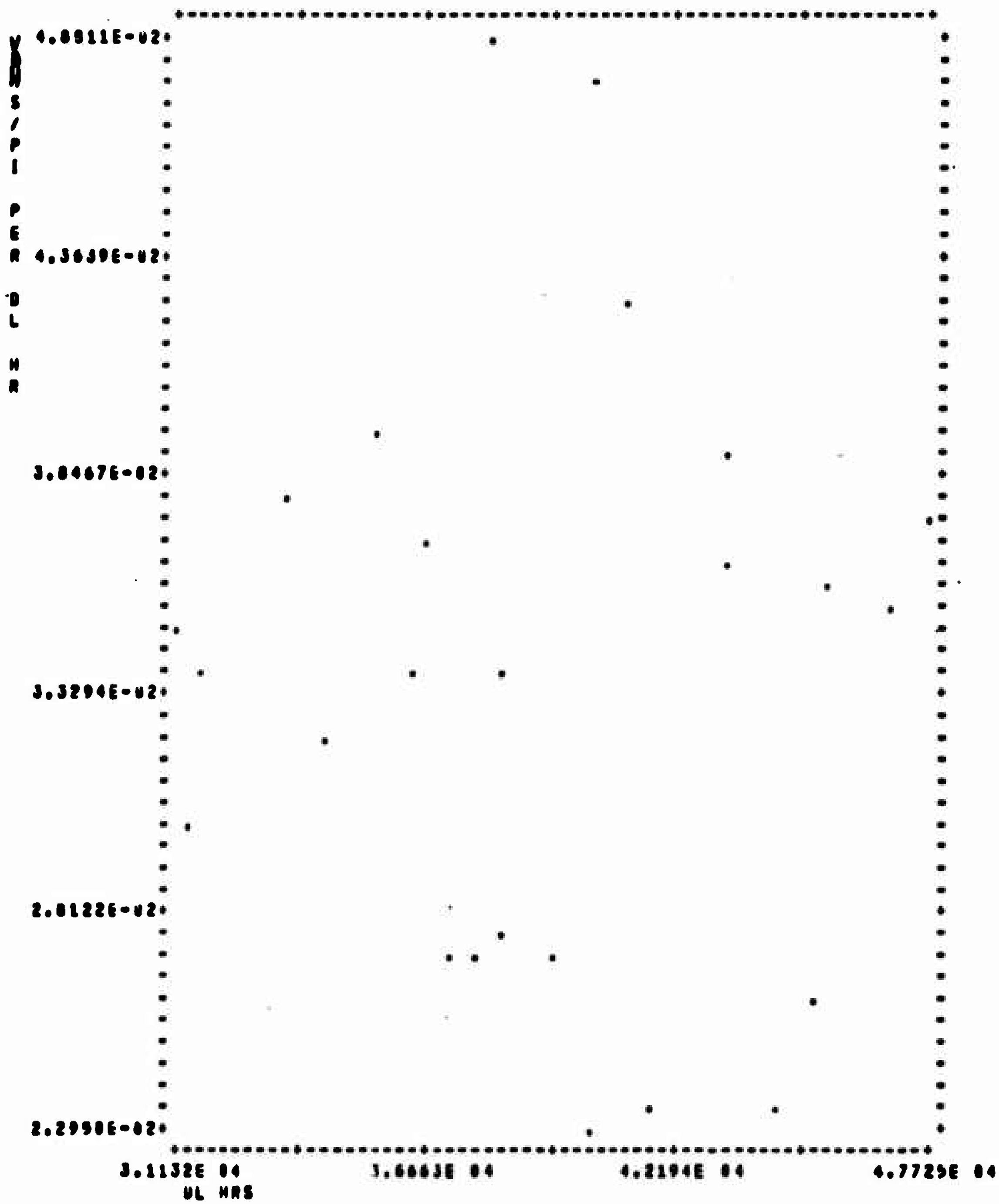
VAR ON KS-10


VDWS/PI PER BL HR
4.6896E-02
4.4739E-02
4.2582E-02
4.0425E-02
3.8269E-02
3.6112E-02
5.8400E 02
2.7130E 03
4.8420E 03
6.9710E 03
UL IKS

VAR OH LGH-25

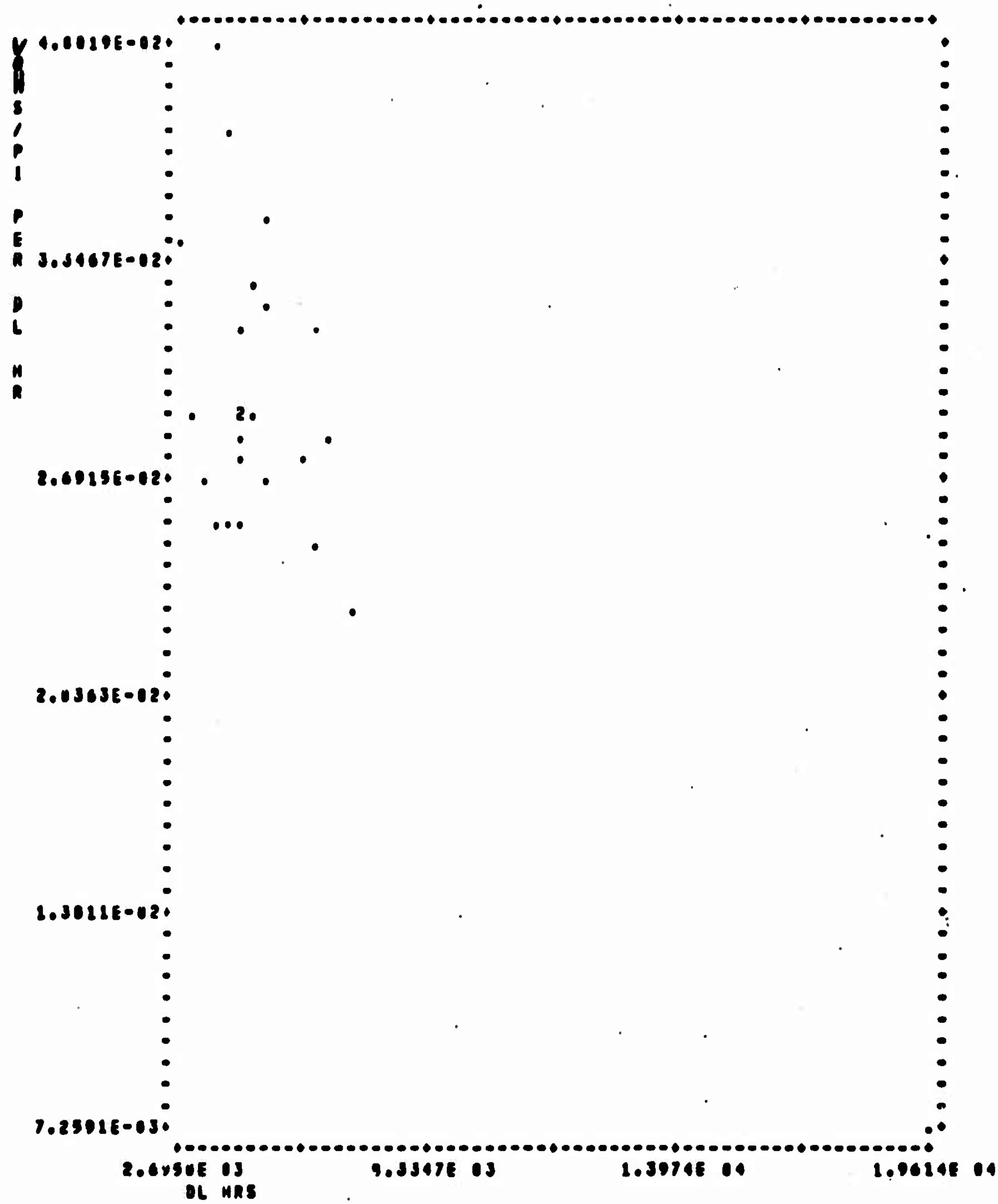

3.9757E-02
3.6882E-02
3.4007E-02
3.1132E-02
2.8257E-02
2.5382E-02
V
A
R
O
H
S
/
P
I
P
E
R
D
L
H
R
0.3730E 03
1.1356E 04
1.4338E 04
1.7321E 04
DL HRS

VAR ON NS-17

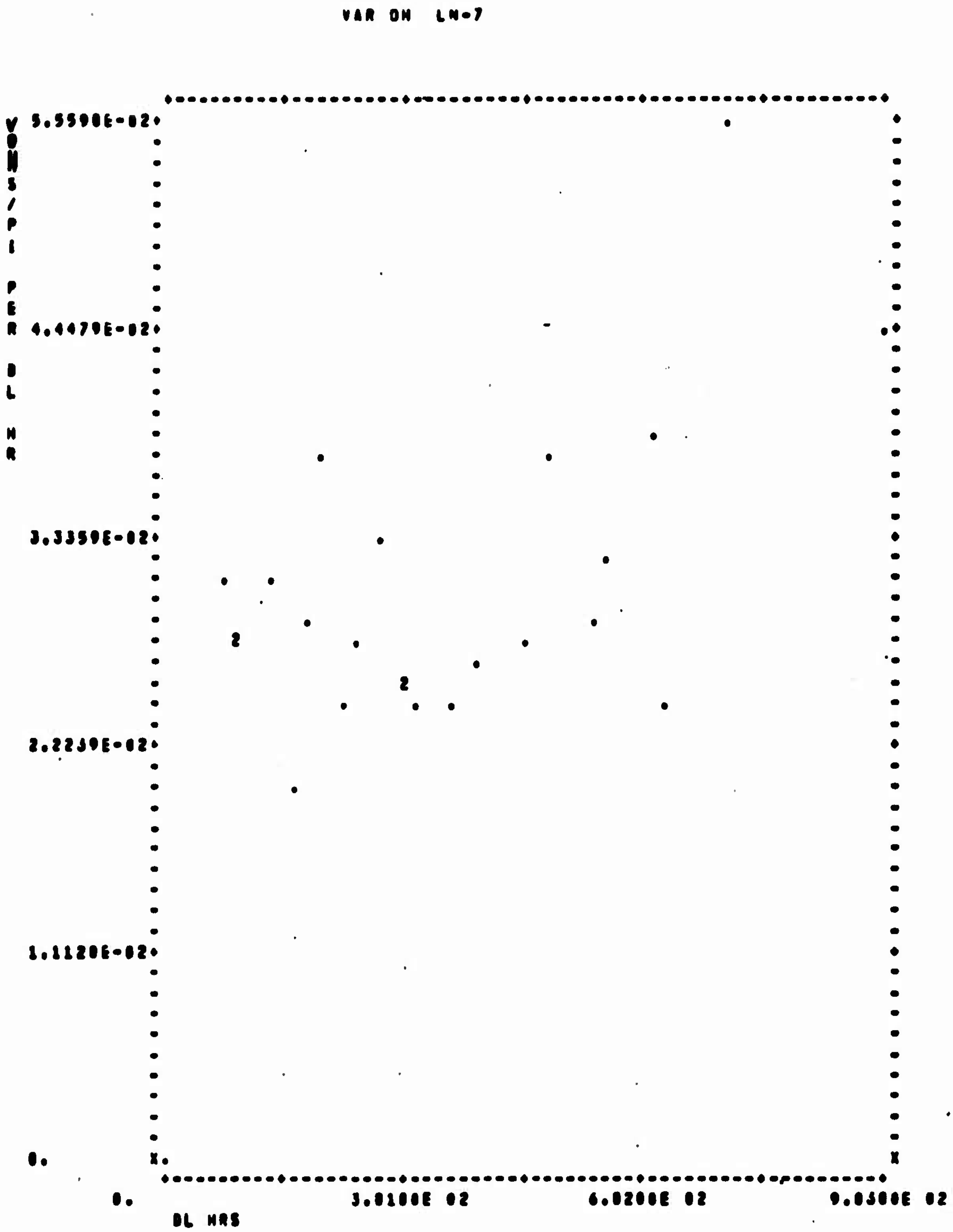


VARHS/PI PER DL HR
4.8811E-02
4.3639E-02
3.8467E-02
3.3294E-02
2.8122E-02
2.2950E-02
3.1132E 04
3.6663E 04
4.2194E 04
4.7725E 04
DL HRS

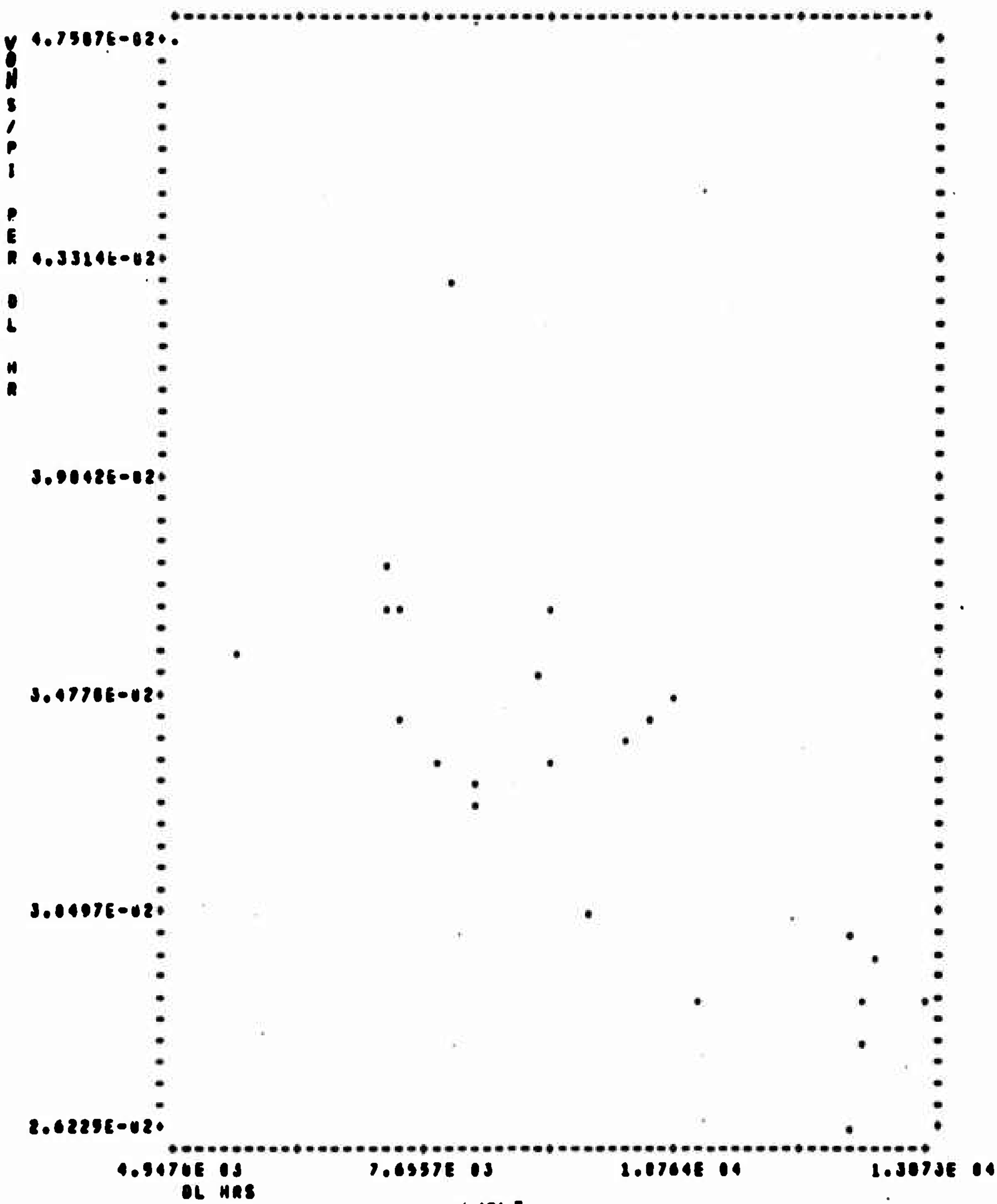
VAR OH LN-14

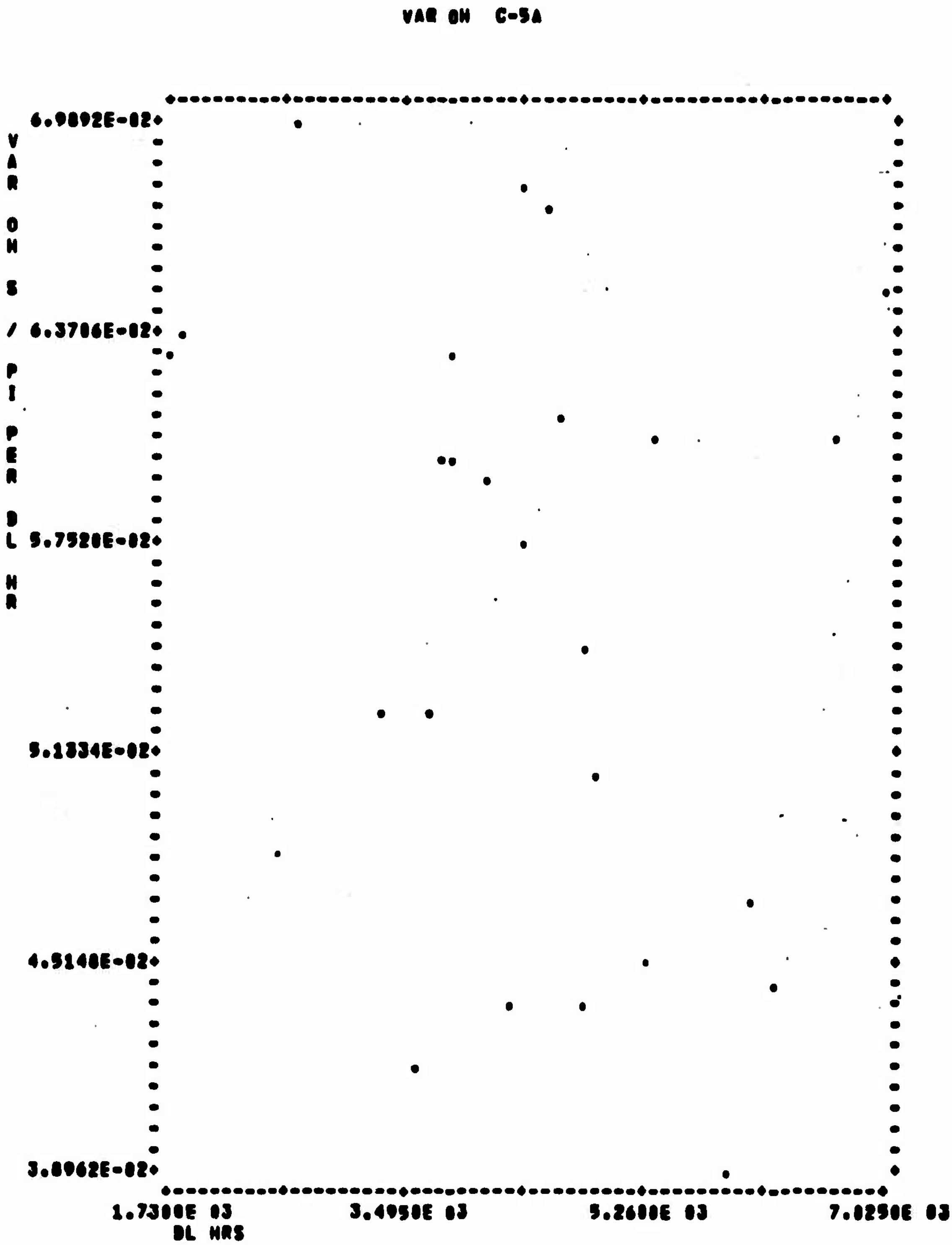


VOHMS/PI PER DL HR
4.0019E-02
3.3467E-02
2.6915E-02
2.0363E-02
1.3811E-02
7.2591E-03
2.6950E 03
9.3347E 03
1.3974E 04
1.9614E 04
DL HRS

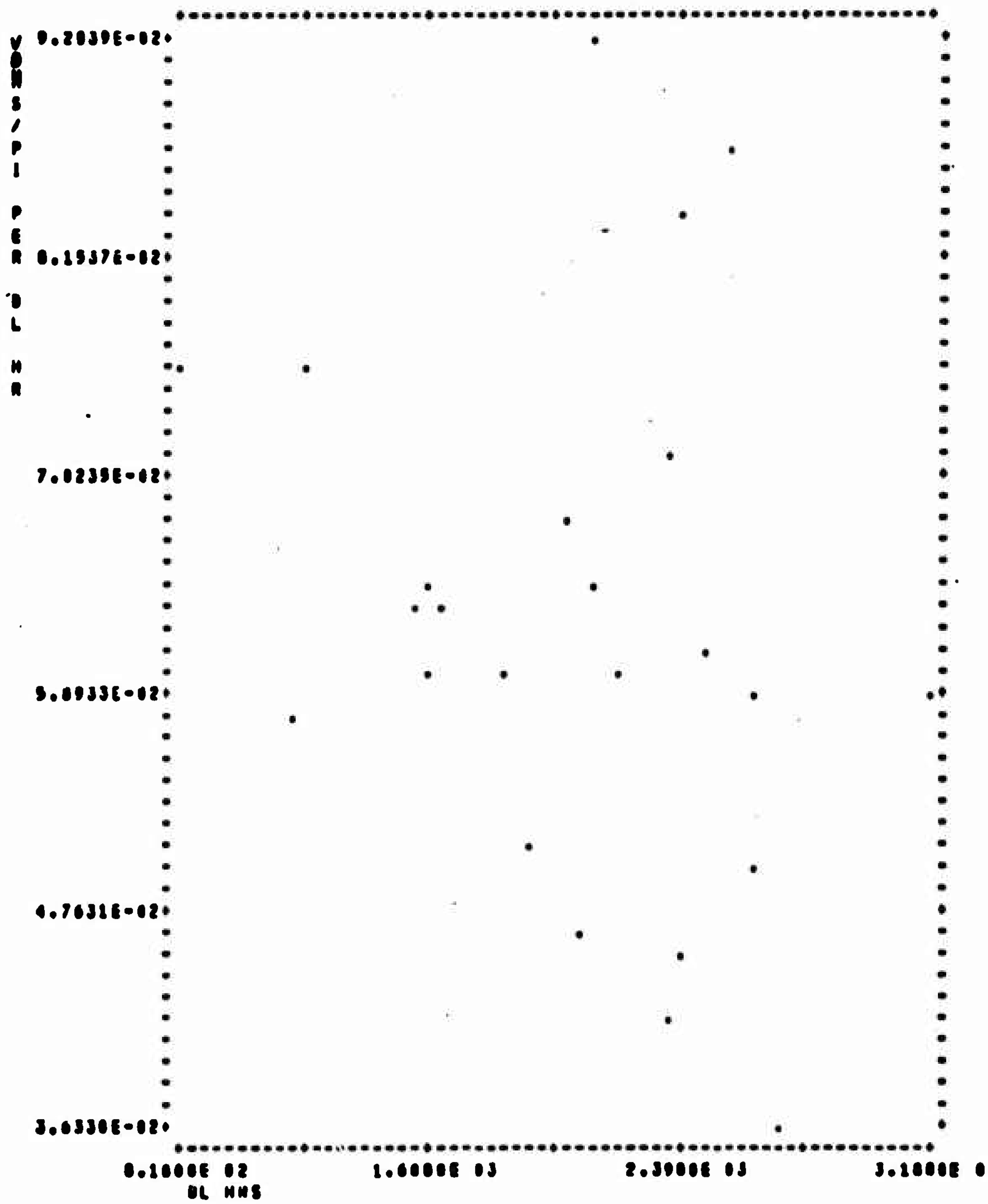

VAR ON LN-7
VOMS/PI PER BL HR
5.5598E-02
4.4479E-02
3.3359E-02
2.2239E-02
1.1120E-02
0.
0.
3.0100E 02
6.0200E 02
9.0300E 02
BL HRS

VAR DH NS-20

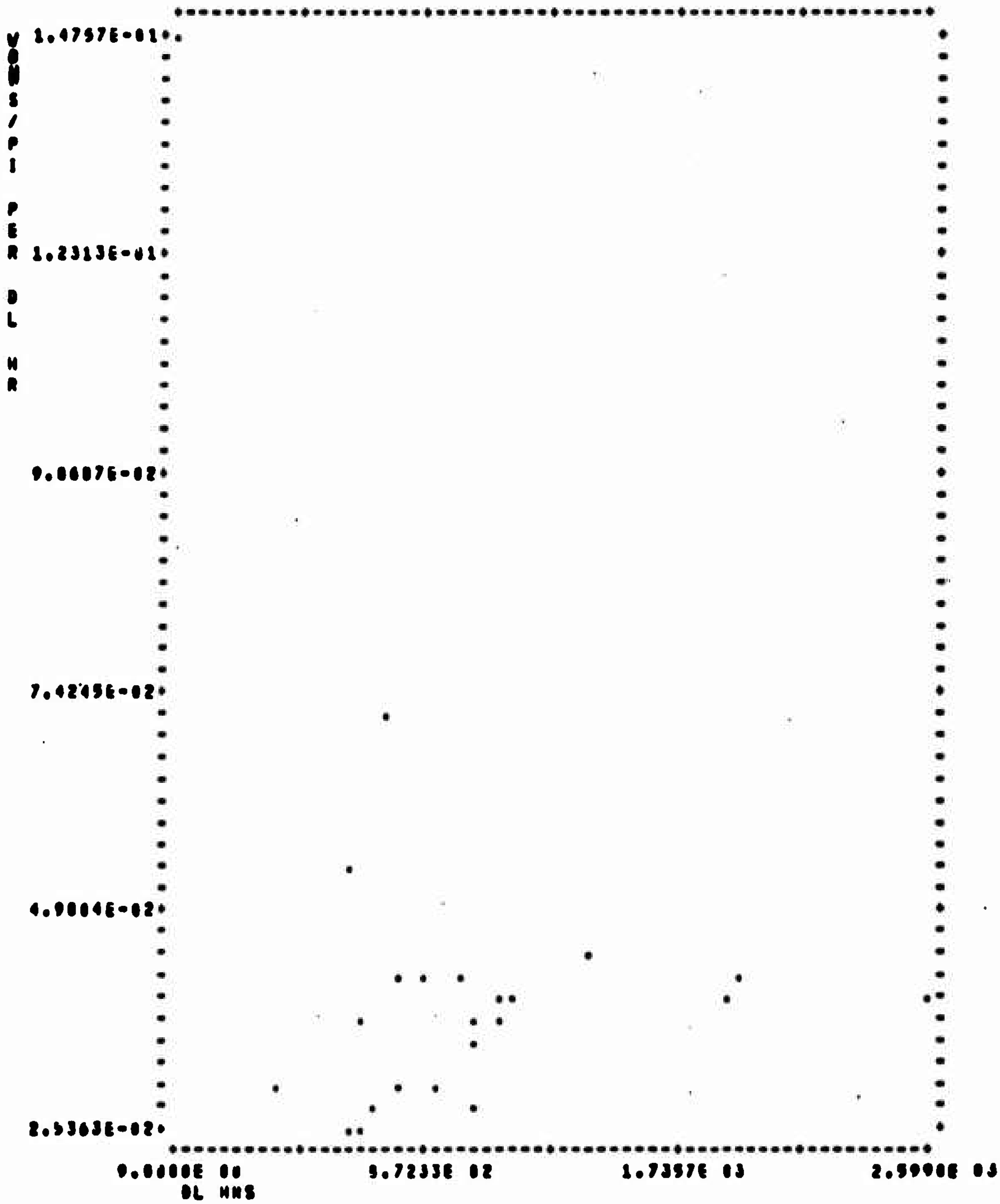

VONS/PI PER BL HR
4.7587E-02
4.3314E-02
3.9042E-02
3.4770E-02
3.0497E-02
2.6225E-02
4.5470E 03
7.6557E 03
1.0764E 04
1.3873E 04
BL HRS


VAR OH C-5A
VAR OHS / PI PER DL HR
6.9892E-02
6.3706E-02
5.7520E-02
5.1334E-02
4.5148E-02
3.8962E-02
1.7300E 03
3.4950E 03
5.2600E 03
7.0250E 03
DL HRS

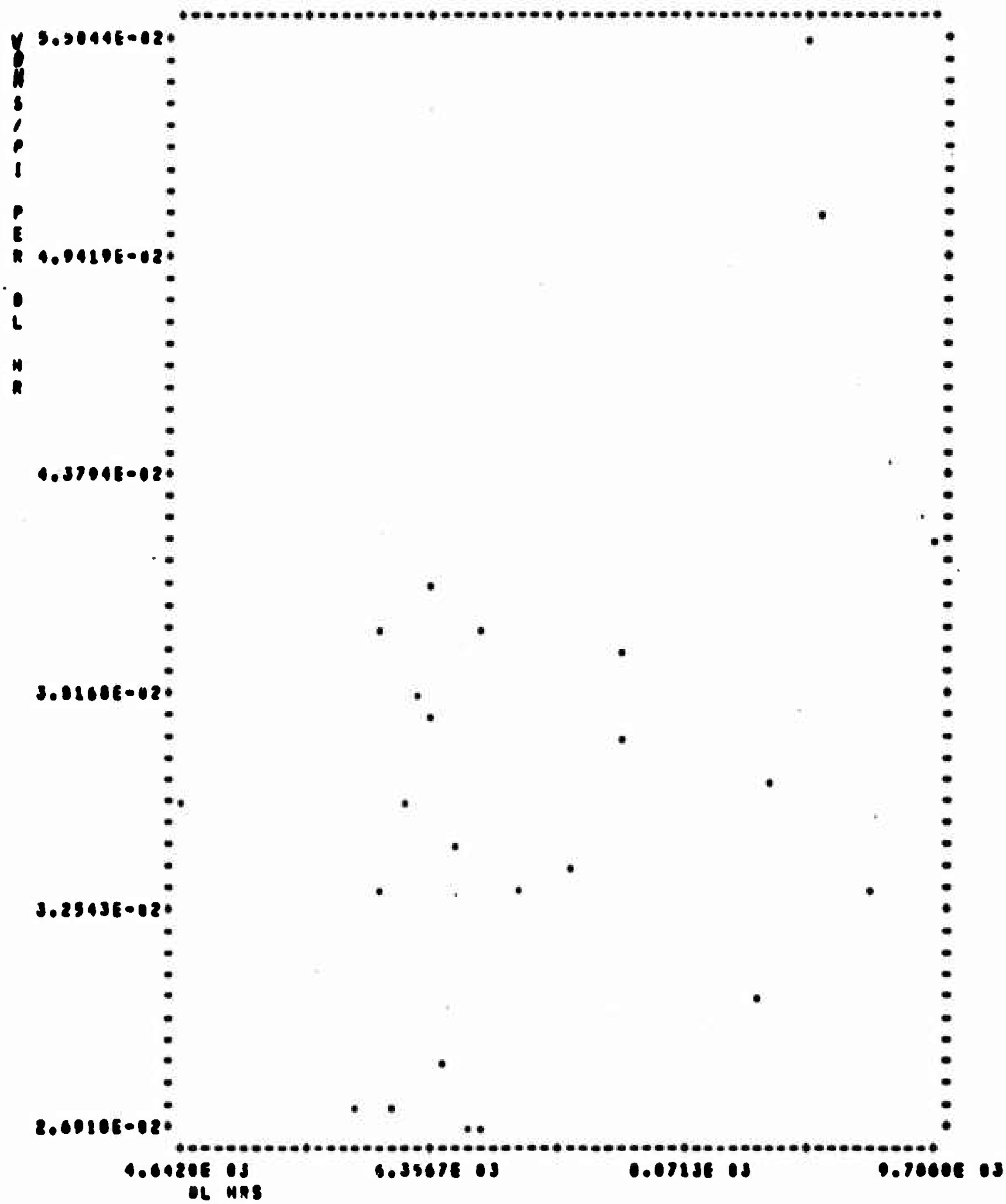
VAR ON N-16


VONS/PI PER BL HR
9.2039E-02
8.1537E-02
7.0235E-02
5.8933E-02
4.7631E-02
3.6330E-02
8.1000E 02
1.6000E 03
2.3900E 03
3.1800E 03
BL HRS

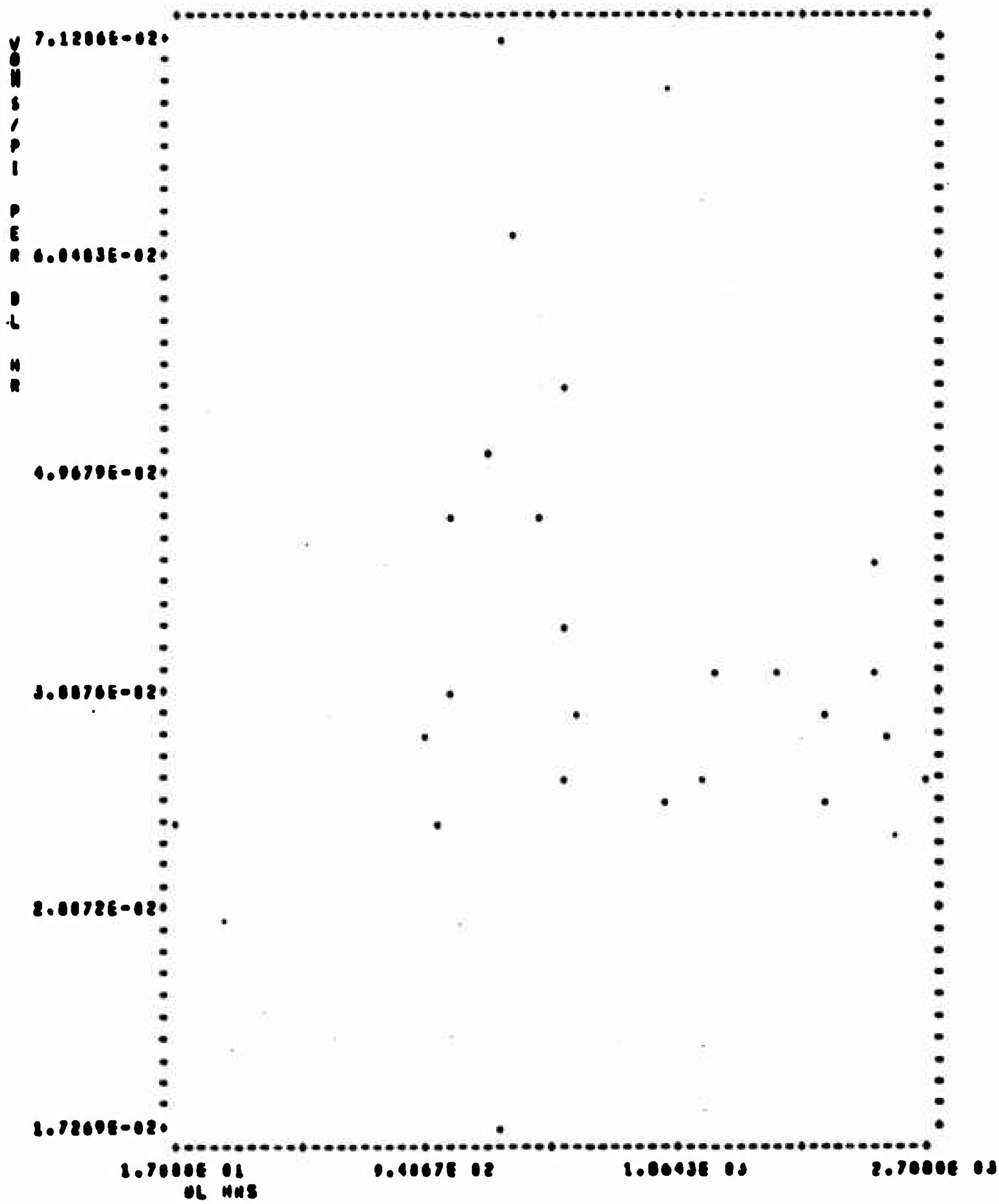
VAR ON KT-71


VOHS/PI PER DL HR
1.4757E-01
1.2313E-01
9.8687E-02
7.4245E-02
4.9804E-02
2.5363E-02
0.0000E 00
5.7233E 02
1.7357E 03
2.5990E 03
DL HRS

VAR ON KT-73


VONS/PI PER OL HR
5.5044E-02
4.9419E-02
4.3794E-02
3.8168E-02
3.2543E-02
2.6918E-02
4.6420E 03
6.3567E 03
8.0713E 03
9.7860E 03
OL HRS

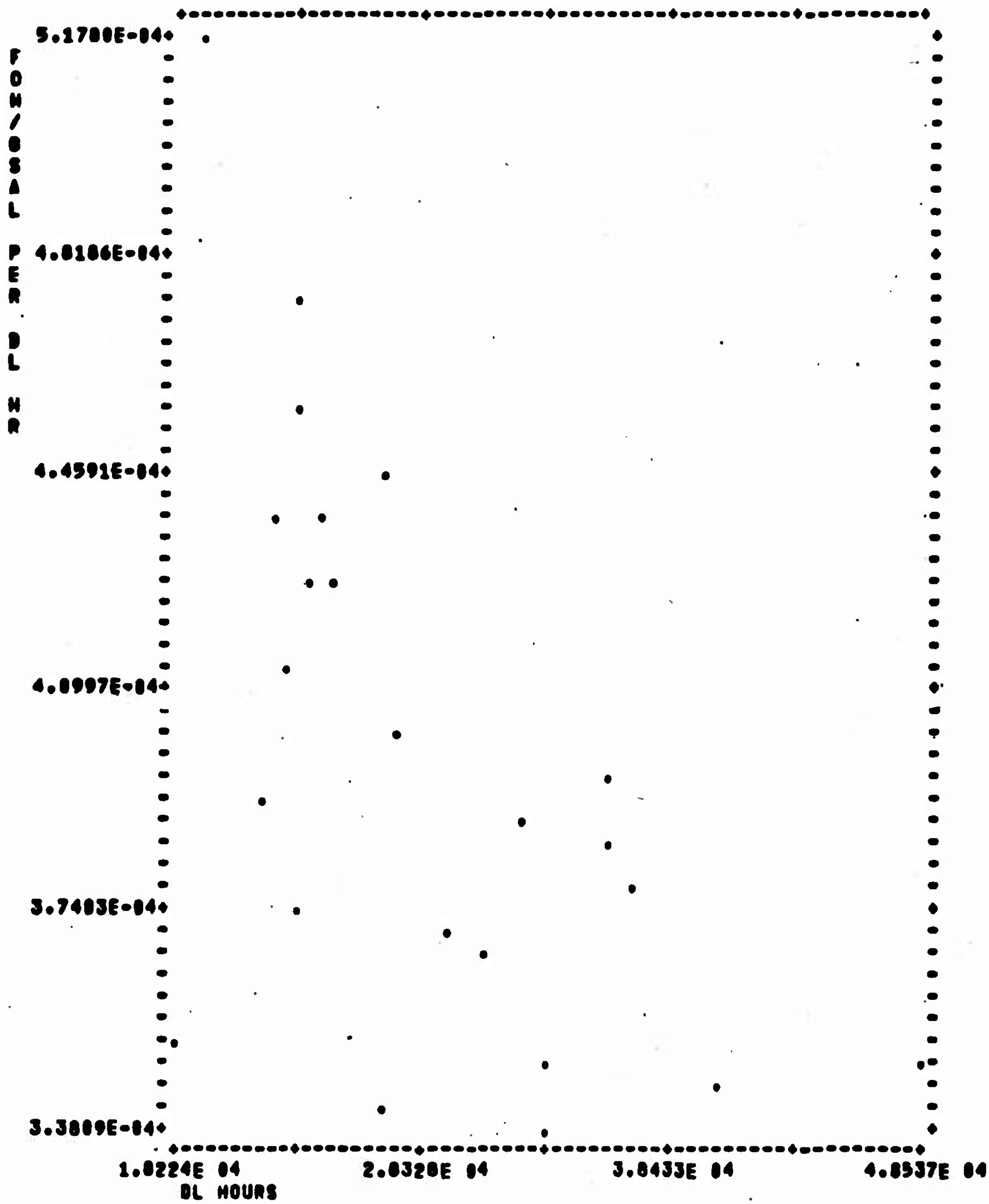
VAR ON N-16DY


VONS/PI PER DL HR
7.1286E-02
6.0483E-02
4.9679E-02
3.8876E-02
2.8072E-02
1.7269E-02
1.7000E 01
9.4067E 02
1.8043E 03
2.7000E 03
UL HNS

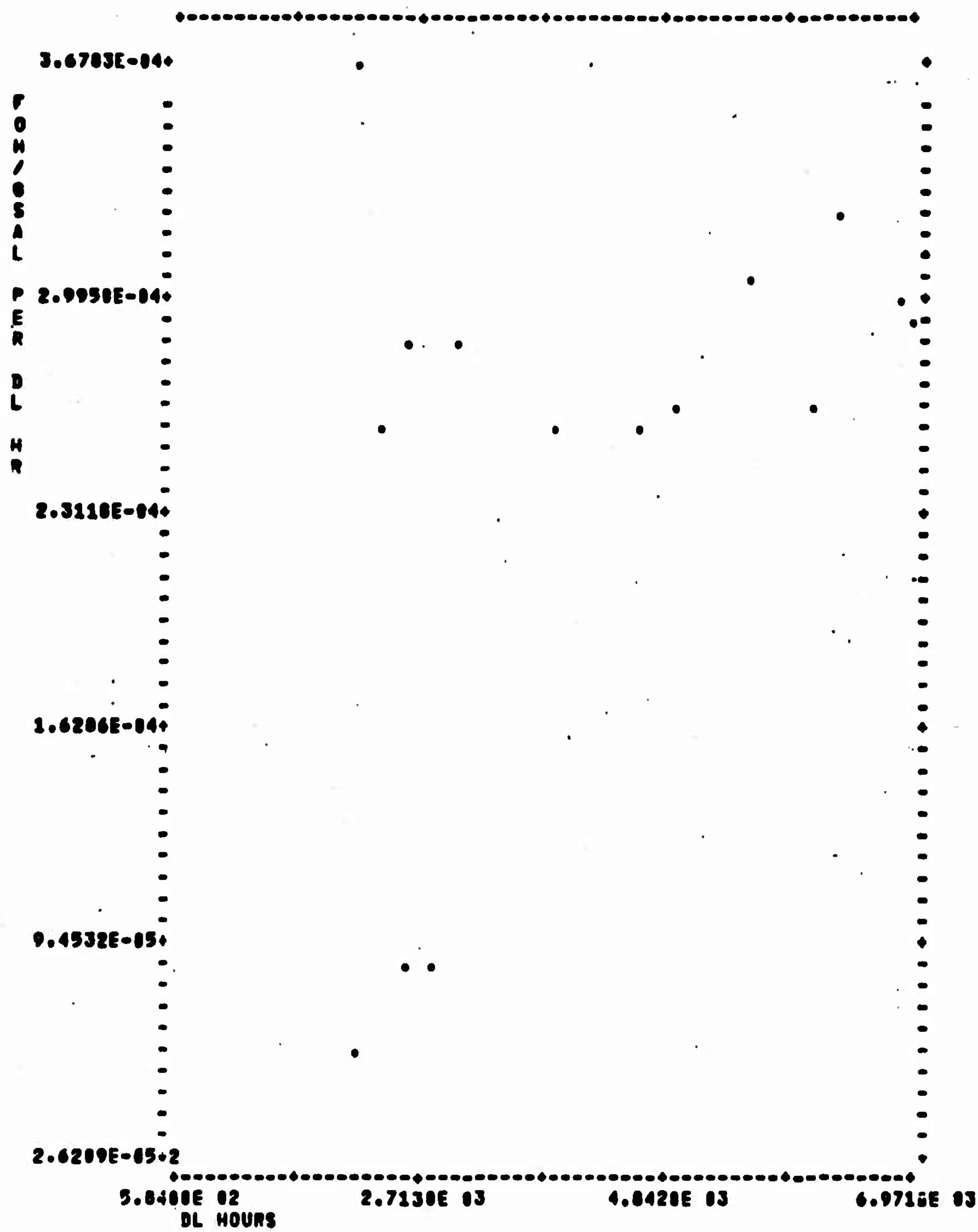
Appendix E

Graphs of Fixed Overhead vs Direct Labor Hours

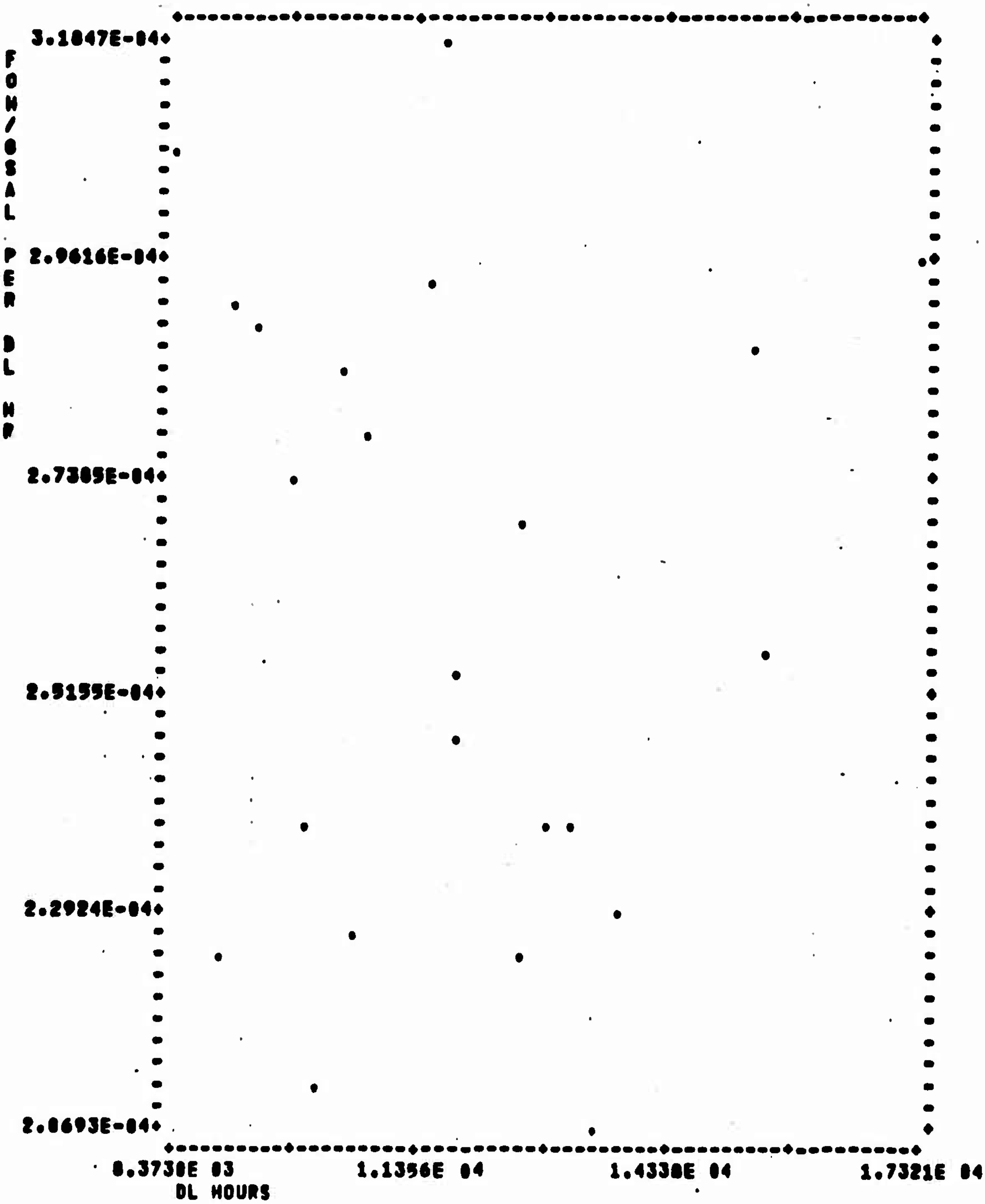
FIXED OH LN-12



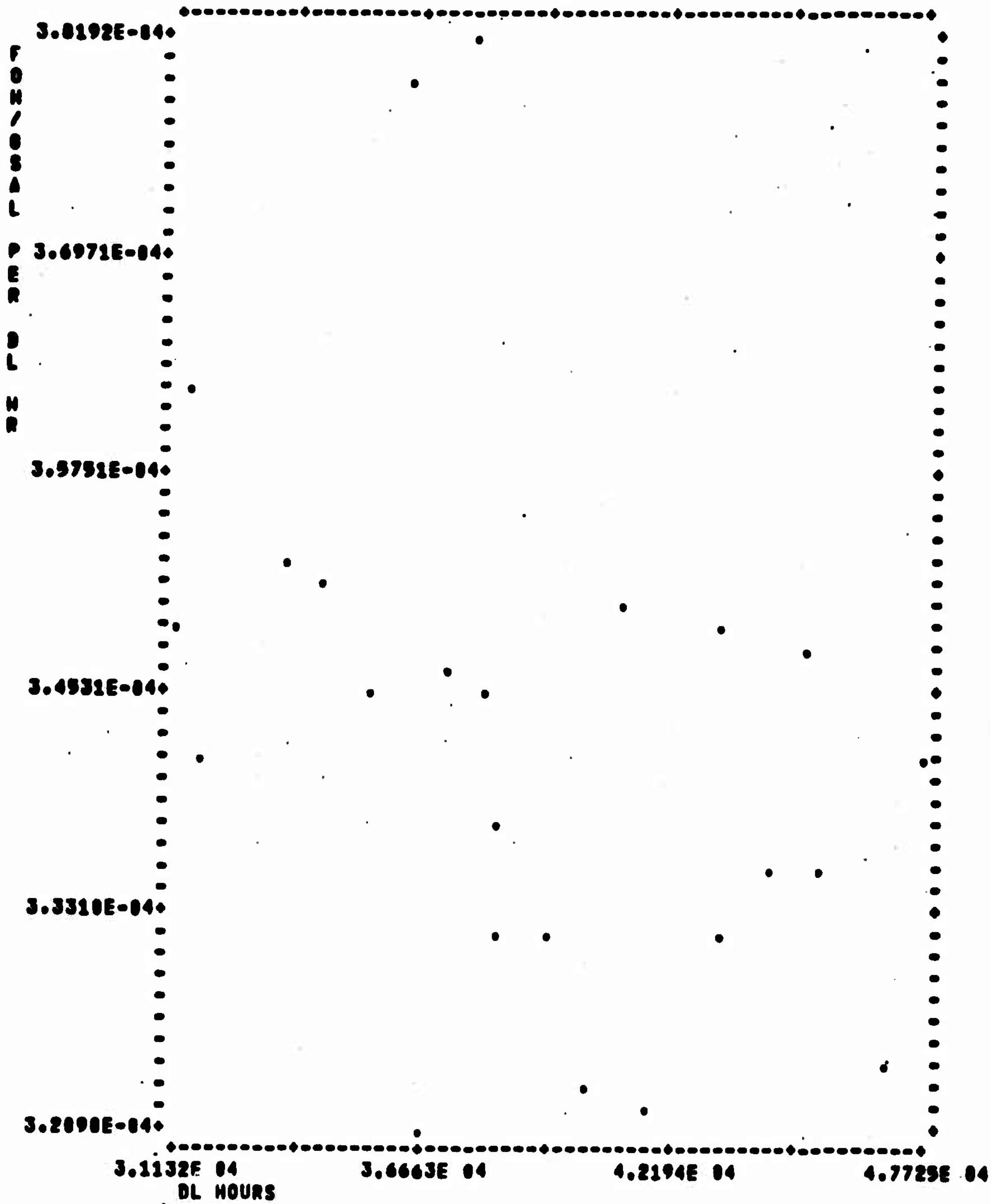
FIXED ON NS-10



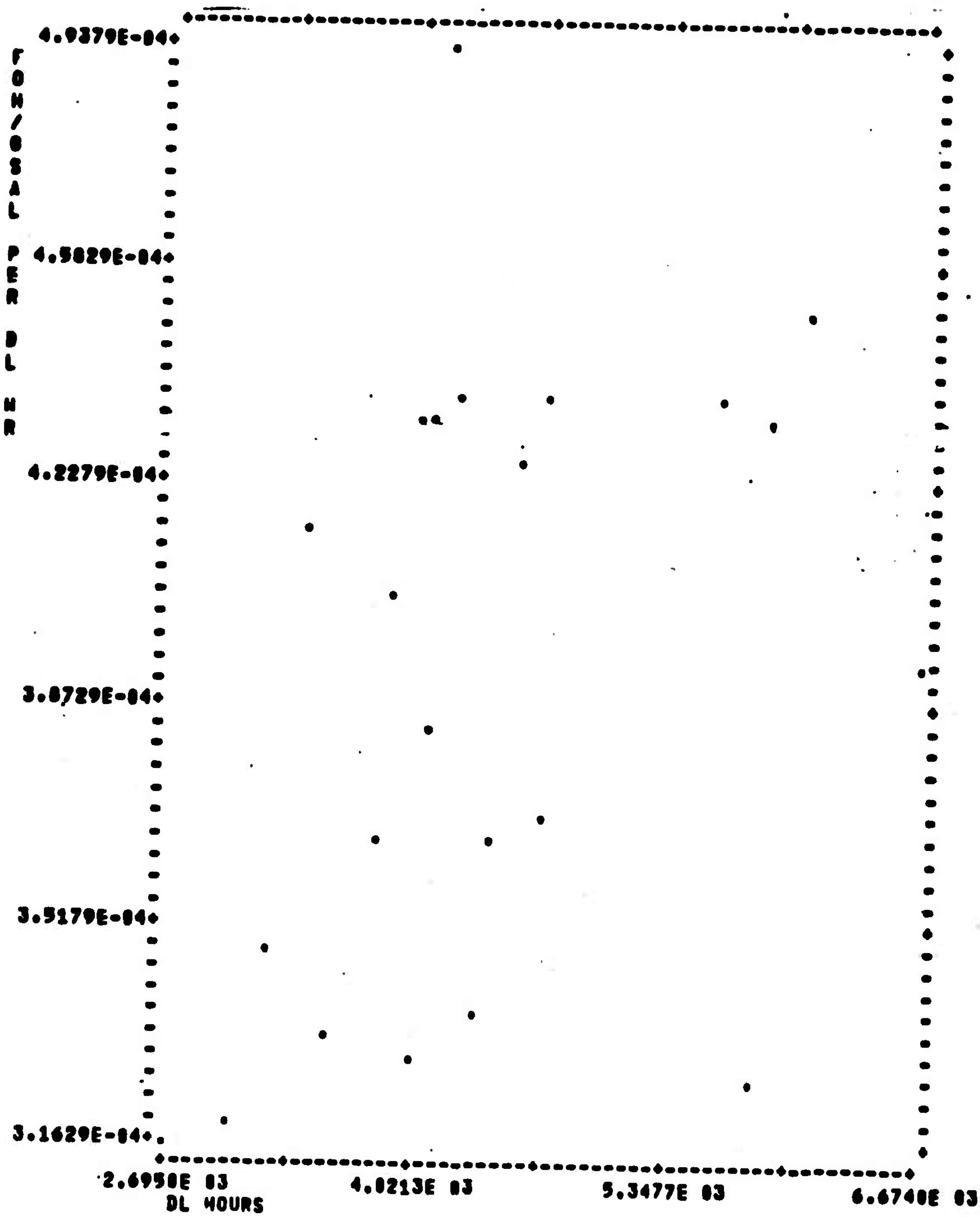
FIXED ON LGN25



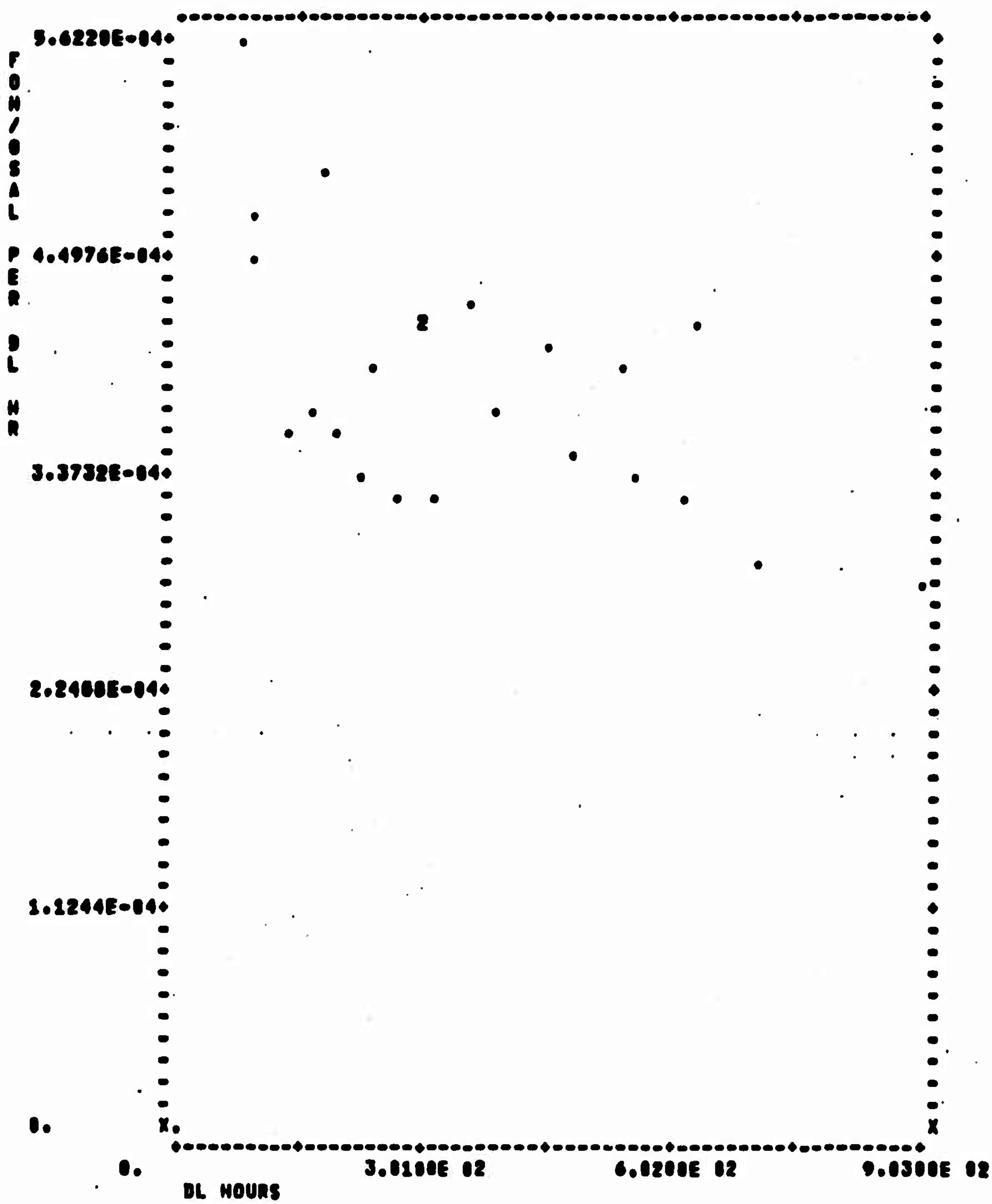
FIXED ON NS-17



FIXED ON LN-14

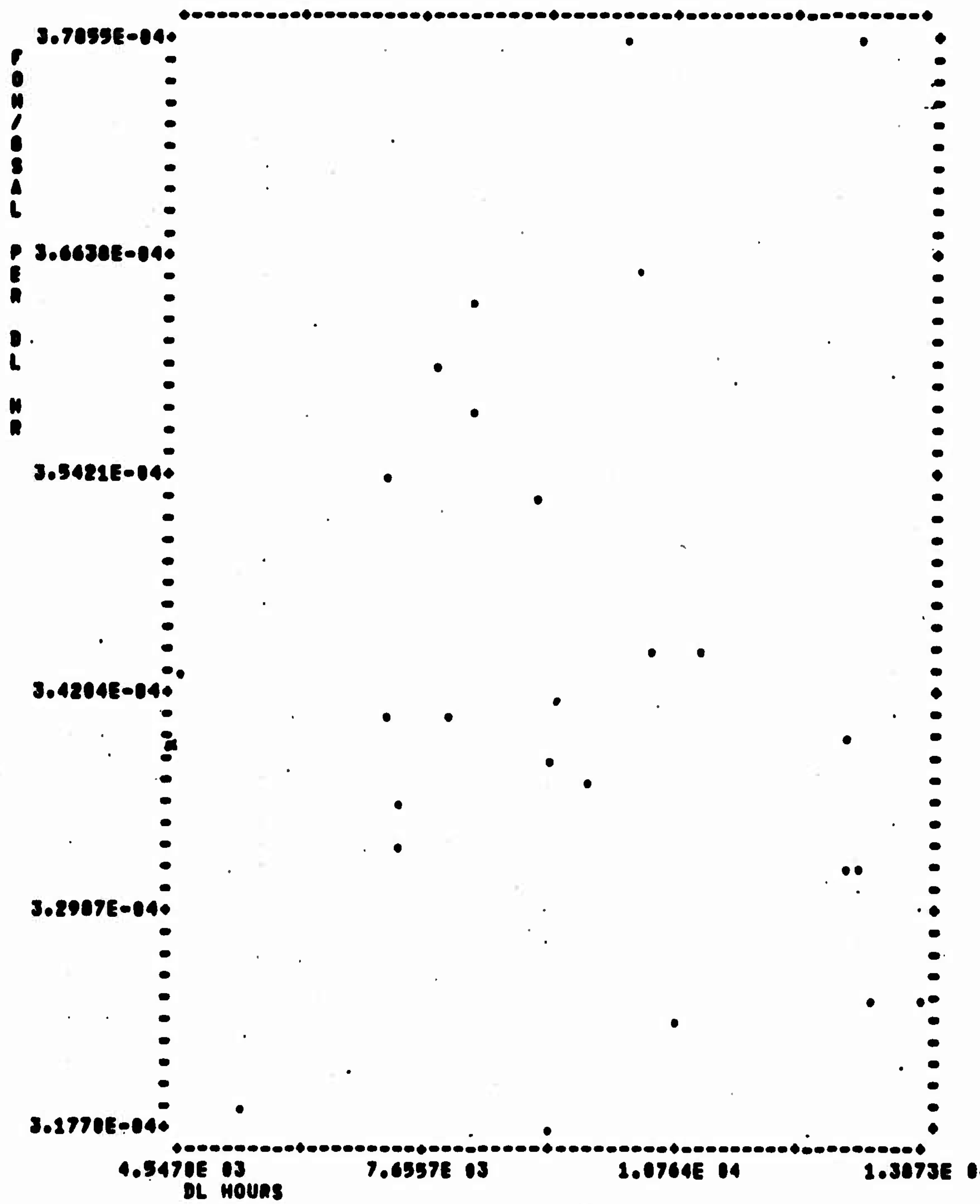


FIXED ON LN-7

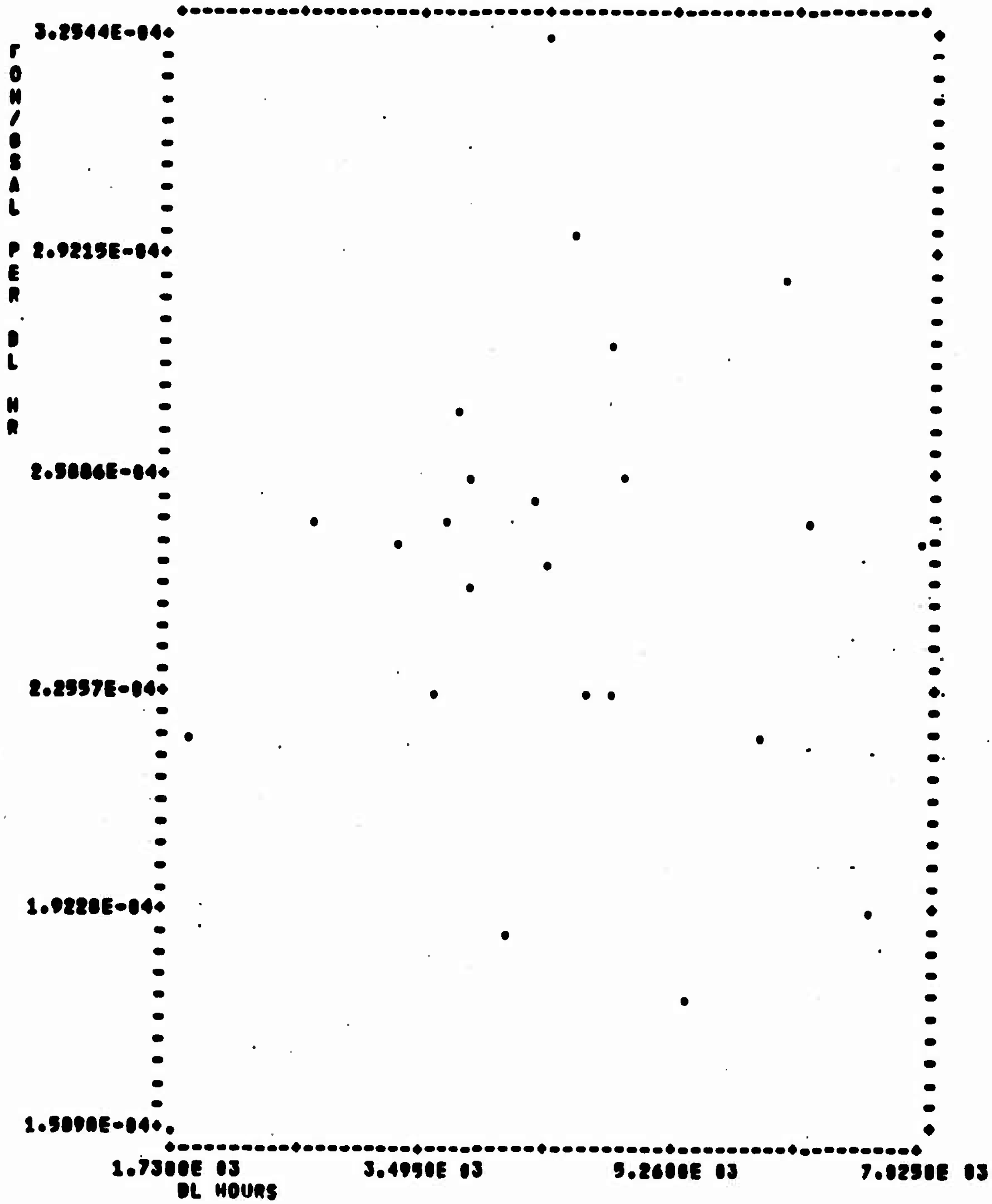


5.6220E-04
4.4976E-04
3.3732E-04
2.2488E-04
1.1244E-04
0.
FON/OSAL PER DL HR
0.
3.0100E 02
6.0200E 02
9.0300E 02
DL HOURS

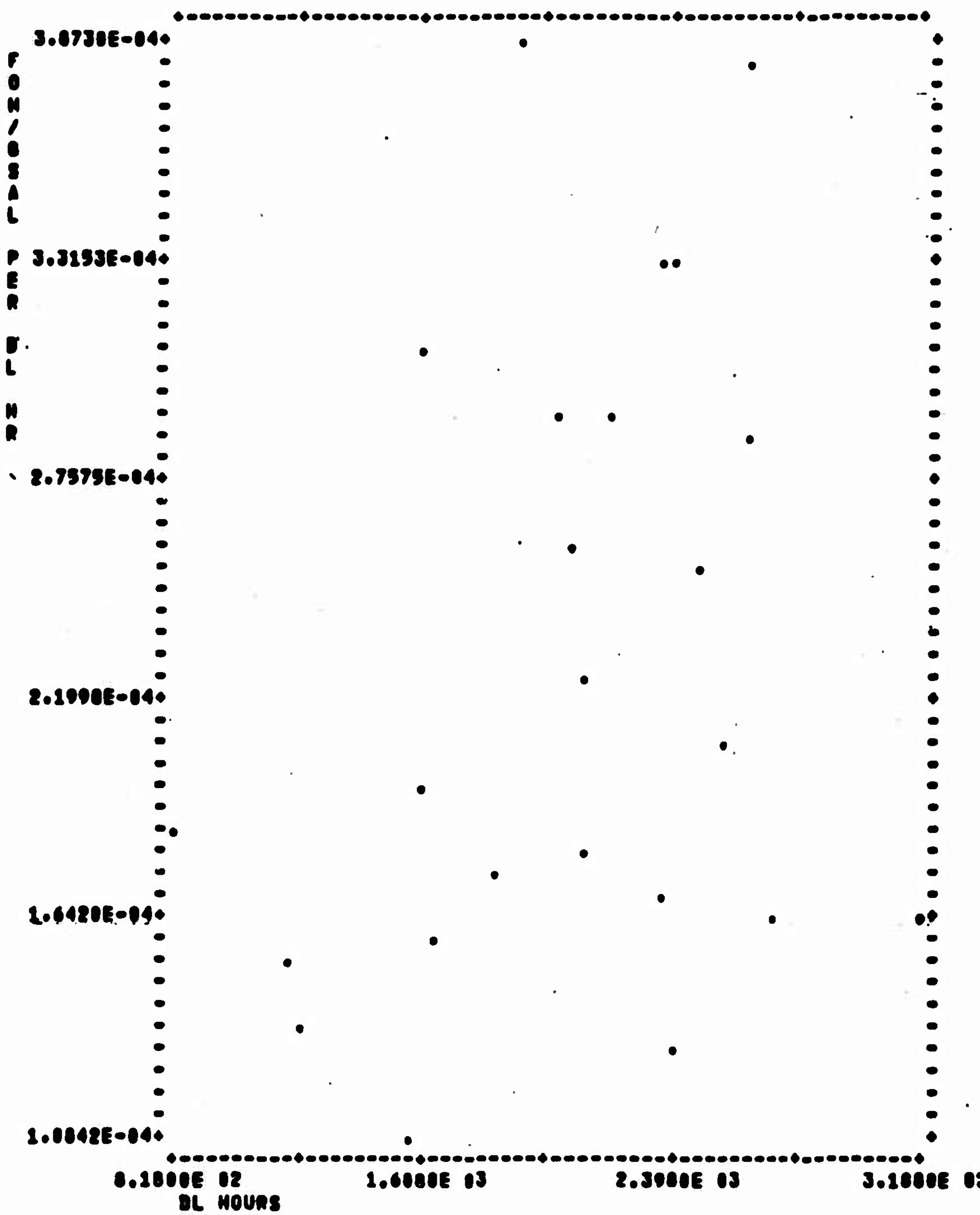
FIXED ON NS-20



FIXED OH C5A

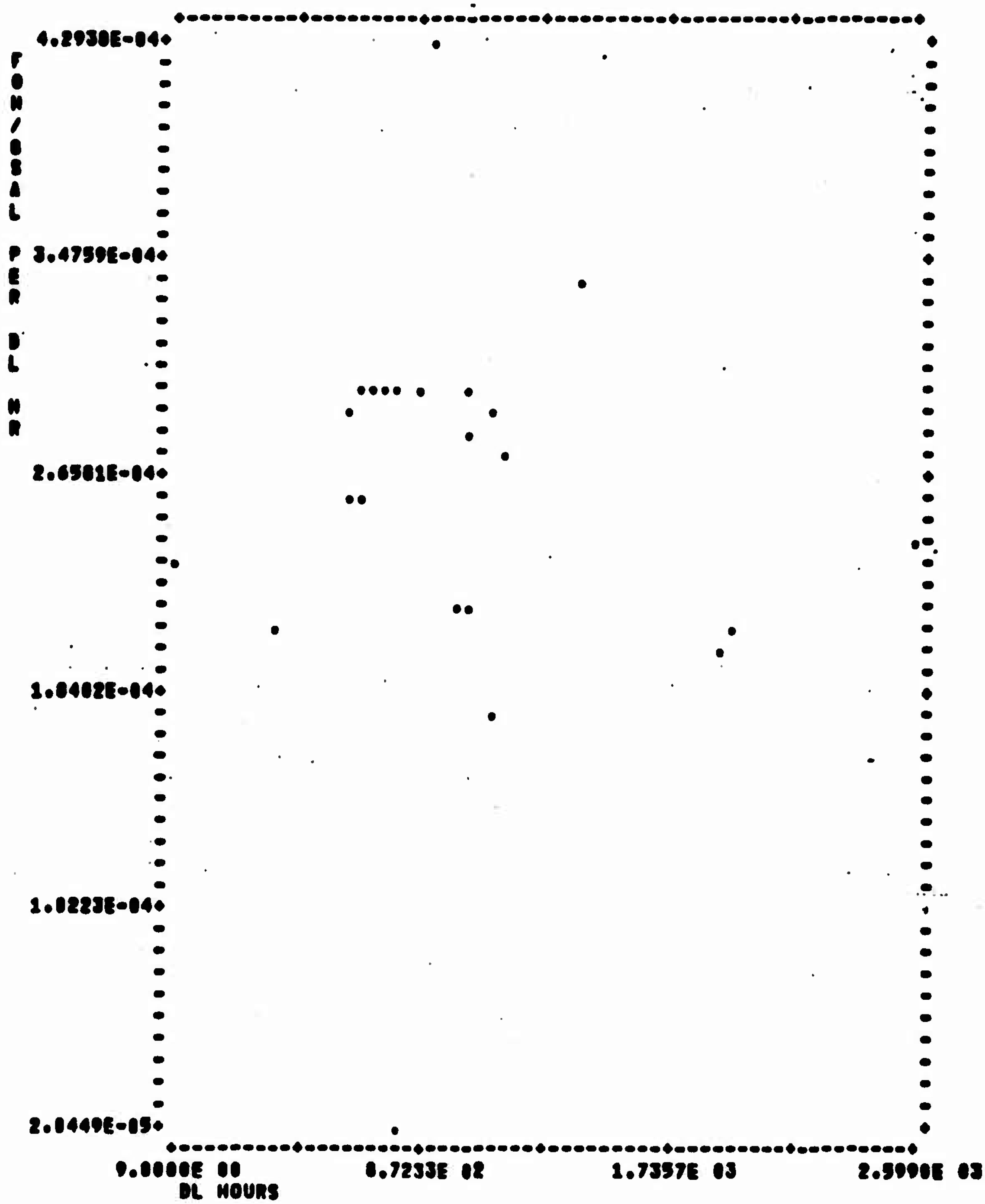

F OH/BSAL PER DL HR
3.2544E-04
2.9215E-04
2.5886E-04
2.2557E-04
1.9228E-04
1.5898E-04
1.7300E 03
3.4950E 03
5.2600E 03
7.0250E 03
DL HOURS

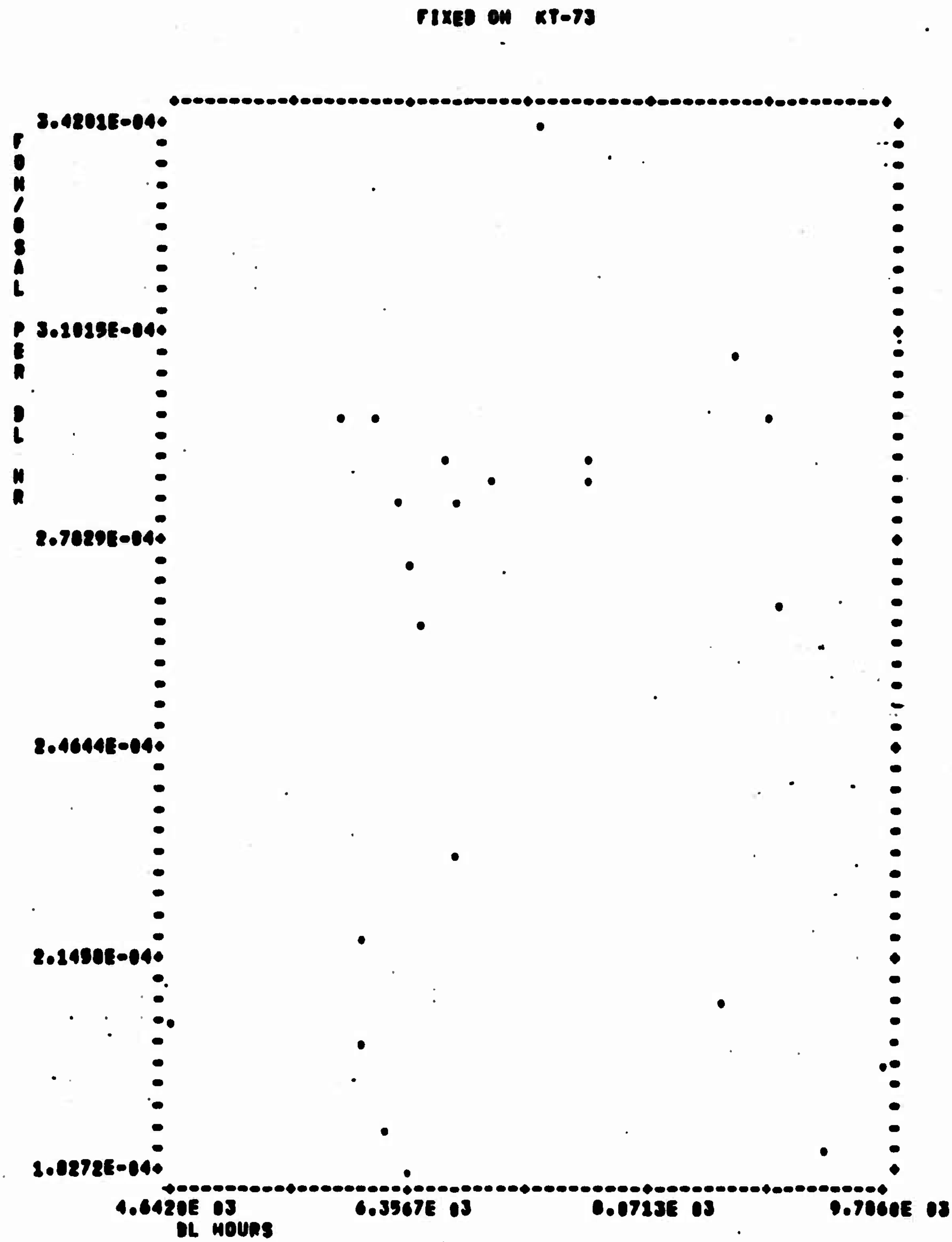
FIXED ON N-16



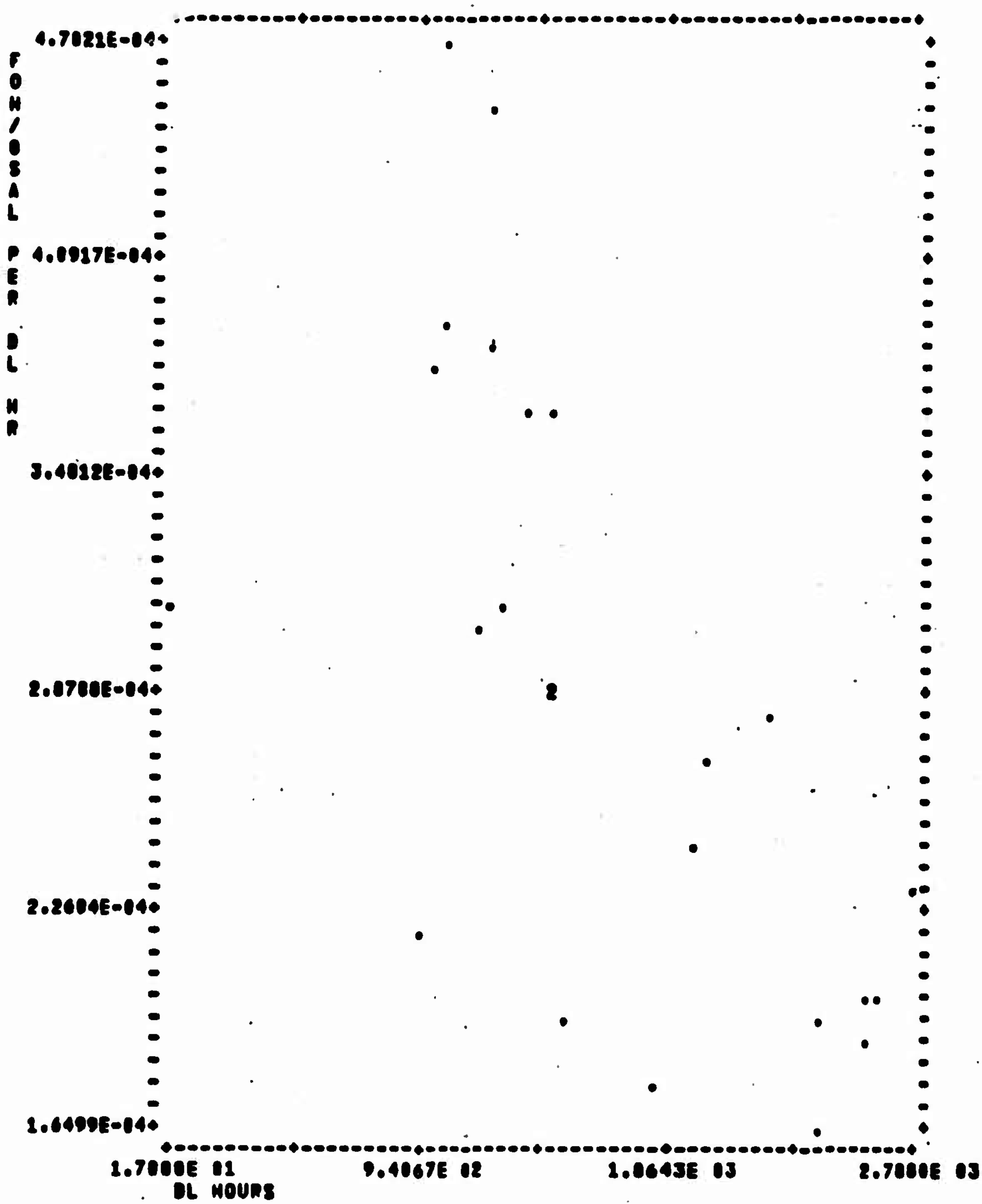
FON/BSAL PER BL HR
3.8730E-04
3.3153E-04
2.7575E-04
2.1998E-04
1.6420E-04
1.0842E-04
8.1800E 02
1.6000E 03
2.3900E 03
3.1800E 03
BL HOURS

FIXED ON KT-71




FIXED ON KT-73
3.4201E-04
3.1015E-04
2.7829E-04
2.4644E-04
2.1458E-04
1.8272E-04
FDH/DSAL PER DL HR
4.6420E 03
6.3567E 03
8.0713E 03
9.7860E 03
DL HOURS

FIXED ON N-166Y



VITA

Donald Allen Clark was born [redacted] After graduating from high school in Battle Ground, Washington in 1962, he entered Clark Junior College in Vancouver, Washington, He graduated from the 2 year program and enlisted in the Air Force in 1964. After serving 18 months in Okinawa, he entered the University of Colorado under the Airman Education and Commissioning Program. In 1968, he graduated with a BS degree in accounting and attended Officer Training School where he was commissioned. He served four years at McCoy AFB, Florida as Management Analysis Officer. In December 1972, he was assigned as an ASTRA officer at DCS/Personnel, Hq. USAF. He began graduate study at the Air Force Institute of Technology in January 1974.

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PII Redacted

This thesis was typed by [redacted]

PII Redacted